PIERS

Progress in Electromagnetics Research Symposium

Proceedings

13 - 17 July, 1998

Cité des Congrès
Nantes, France

Volume 1

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	22 July 1998	Conference Proceedings

4. TITLE AND SUBTITLE

Progress in Electromagnetics Research Symposium (PIERS) 98

5. FUNDING NUMBERS

F61775-98-WE031

6. AUTHOR(S)

Conference Committee

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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1 Chemin Desvallieres
Paris, Ville d'Avray 92140
France

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

CSP 98-1031

11. SUPPLEMENTARY NOTES

Proceedings contained in three volumes.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

The Final Proceedings for Progress in Electromagnetics Research Symposium (PIERS) 98, 13 July 1998 - 17 July 1998

This is an interdisciplinary conference. Topics include: electromagnetic theory, computational techniques, guided waves and propagation, antennas, components, composite, and complex materials, signal processing, polarimetry, remote sensing, wireless communication systems, measurement techniques.

14. SUBJECT TERMS

Antennas, Electromagnetics, Electromagnetic Materials, Communications, C3I

15. NUMBER OF PAGES

1270

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

PIERS 1998

Progress In Electromagnetics Research Symposium

PROCEEDINGS

Volume 1

July 13-17, 1998
Nantes, France

Organised by
The Electromagnetics Academy
IRESTE, Université de Nantes
CESBIO, CNES-CNRS-Université Paul Sabatier, Toulouse
Institut Universitaire de Technologie, Université de Paris X

PIERS 1998

Progress In Electromagnetics Research Symposium

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MENRT, Directions de la Recherche et de la Technologie

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European Commission : JRC and DG XII

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Progress in Electromagnetics Research Symposium
July 13-17, 1998
Nantes, France

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FRIDAY, JULY 17, PM

General Chairman's Welcome

After Cambridge, (USA, 1989 and 1991), Pasadena (USA, 1993), Noordwijk (The Netherlands, 1994), Seattle (USA, 1995), Innsbruck (Austria, 1996), Hong Kong (January 1997) and Cambridge (USA, July 1997), the 1998 Progress in Electromagnetics Research Symposium will be organized in France from 13 July through 17 July 1998. We are honored to host PIERS 1998 in Nantes.

On behalf of the International and National Organizing Committees of PIERS'1998 I would like to welcome you to the ninth PIERS, the third PIERS held in Europe. For the first time a 12-day conferences on Electromagnetics will be organized in European Countries with the International Workshop on Finite Elements for Microwave Engineering, 10-1 July 1998, in Poitiers, France, PIERS'1998, 13 to 17 July in Nantes, France and PIERS Workshop on Advances in Radar Methods, 20-22 July, Baveno, Italy. Several workshops have been organized and I would like to draw your attention in particular to the 4th International Workshop on Radar Polarimetry and the Workshop on Complex Media and Measurement Techniques included in PIERS'1998. Two one-day workshops presented by invited expertshave been organized on important topics.

PIERS'1998 offers a broad spectrum of sessions in various fields of electromagnetic theory and its new exciting applications. It encourages interaction between different fields and reports most recent advances and progress in electromagnetics. More then 1000 papers have been received from 46 countries in the world. More than 600 persons are, already, pre-enregistered. The Technical Program Committee, under the chairmanship of Dr. Thuy Le Toan, together with more than 100 sessions organizers, has done an outstanding job of arrangin sessions covering all areas of electromagnetic research. Most of these sessions are organized by distinguished experts in the field with invited specialists reporting on their most recent work. As far as possible, the sessions have been arranged in homogeneous thematic topics to assist you, the conference participants in your individual selection.

We have also scheduled several social events for relaxation and enjoyment during the week. The Mont Saint Michel tour, the walking tour of Nantes, the guided tour of graves vineyards and the Chateaux de la Loire tour, the Loire valley tour are wonderful events not to be missed by you and your companions. A gala dinner is organized on Wednesday, 15 July in the "Chateau de la Poterie" after a lovely river on the Erdre river.

PIERS'1998 could not have been organized without the sustained efforts of the Session Organizers. I am very grateful for their valuable contribution to the symposium. I would like to take this opportunity to thank the members of the Technical Program Committee and the National and International Steering Committees, chaired by Dr. Thuy Le Toan and Pr. Joseph Saillard for their excellent work in preparing and coordinating the program and in organizing the PIERS'1998 web site. I would also like to thank the members of the Organizing Committee who readily accepted the considerable workload in administration and management of the symposium and in the organization of all the social events. Without the financial support of local, national and international agencies we could not organized in PIERS'1998 Symposium in France at such low registration rates. This financial support has also allowed us to invite more than 10 specialists in electromagnetics from the former SOVIET union to share their expertise. We wish to thanks all these agencies for their contribution to the success of the Symposium.

I hope you will find this symposium to be great scientific interest and benefit as well as an enjoyable social occasion to meet friends and colleagues and to discover the beauty of this part of France.
Thank you for joining us.

A. PRIOU
PIERS'1998 General Chairman

PIERS TECHNICAL PROGRAM

Monday, July 13, AM 10:00-12:20
Room Auditorium 800

10:00-11:30

WELCOME AND OPENING CEREMONY

11:30-12:20

Past and Future in Electromagnetics

Keynote Adress :

Professor Michel NEY
Laboratory for Electronics and Communication Systems (LEST)
Ecole Nationale Supérieure des Télécommunications de Bretagne (ENST-Br.)
Brest, FRANCE

Session A01
Monday, July 13, PM 13:40-17:40
Room 300
Rough Surface Scattering And Related Problems

Organiser : A. A. Maradudin
Chairs : A. A. Maradudin, E.R. Mendez

Banded Method of Ordered Multiple Interaction for the Scattering of EM Waves from a Rough Surface

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A Banded Method of Ordered Multiple Interaction (MOMI) is presented for the scattering of electromagnetic waves from a one-dimensional, perfectly-conducting, rough surface that scales as *NlogN*. The improvement over the N^2 scaling of the standard MOMI is achieved by using a banded forward and backward substitution. The MOMI requires the solution of the matrix equation $(\mathbf{I}-\mathbf{K})\mathbf{a} = \mathbf{b}$ where $\mathbf{a}$, $\mathbf{b}$, and $\mathbf{K}$ are the unknown vector, known vector, and the lower (or upper) triangular matrix, respectively. The backward (forward) substitution solution requires the elements of the unknown vector to be obtained sequentially. To achieve the *NlogN* scaling, we first break a vector into a two-component form, $\mathbf{a} = (\mathbf{a}_1,\mathbf{a}_2)$. The original matrix equation becomes two coupled matrix equations. One equation can be solved independent of the other. Once this equation is solved, the second equation can be solved. For an upper (lower) matrix $\mathbf{K}$, the second equation for $\mathbf{a}_1$ ($\mathbf{a}_2$) has the term $\mathbf{K}_{12}\mathbf{a}_2$ ($\mathbf{K}_{21}\mathbf{a}_1$). This term can be evaluated using a banded matrix approach that will scale only as *NlogN*. The banded matrix approach divides the kernel $\mathbf{K}$ into a near and far region. The near region, chosen to be small, is evaluated exactly. The far region is evaluated by convolution and FFT. To get the kernel into convolutional form, the part of the kernel that depends on $\mathbf{r}-\mathbf{r}'$ is Taylor expanded around $z-z'= 0$. A finite number of terms, depending on the size of the nearby region as well as the surface roughness, are kept. Besides the matrix-vector multiplication, we have two equations to solve. This two-component approach can be recursively carried out on each of the two equations until a vector of small size, typically the size of the nearby region, is reached.

Backscattering by Multiscale Surfaces at Grazing Angles of Incidence

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The backscattering of light at grazing angles of incidence has historically been a topic of great interest in remote sensing. Many radar systems operate in this kind of geometry. Grazing incidence problems might also become relevant in more modern applications such as advanced technologies in ground transportation, and multiple-satellite communication systems.

In recent years, numerical techniques have been developed, and used in rigorous analysis of the problem of scattering by randomly rough one-dimensional surfaces. These methods have been used to test the validity of the classical approximate approaches to the scattering problem. Unfortunately, in their usual formulation, these methods have proved to be inaccurate for large angles of incidence and scattering.

In this paper we will present grazing angle of incidence calculations with multiscale surfaces, obtained by numerical methods. The main motivation for this work is provided by the need to model the signals obtained by oceanographic radars in near grazing geometries. In order to avoid the problems associated with the numerical treatment of a finite-length surface at large angles of incidence, we study the related problem of scattering from a periodic random surface. The scattering problem is then reduced to that of solving a matrix equation for the Bragg waves diffracted by each realization of the grating. The results obtained with the proposed numerical approach are compared with results obtained with other formulations of the scattering problem.

Scattering from Randomly Rough Metal Surfaces : SERS Electromagnetic Mechanism

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The appearance of large electromagnetic (EM) fields in the vicinity of rough metal substrates, upon which an incoming beam is impinging, plays a relevant role in Surface-Enhanced Raman Spectroscopy (SERS). In this paper we analyze this EM mechanism near randomly rough surfaces with Gaussian statistics possessing fractal properties analogous to those observed in colloidal aggregates or other metal substrates commonly used in SERS experiments. By means of numerical simulation calculations based on the Green's theorem integral equation formulation, the linearly polarized electromagnetic field scattered from one-dimensional, randomly rough metal surfaces is obtained. In the case of p (TM) polarization, for which large magnetic, near field intensities have been reported due to the roughness-induced excitation of surface-plasmon polaritons, we study the enhancement of the perpendicular and parallel components of the electric field, which are crucial to the vibration and polarization selectivities in SERS. In addition to this passive picture of the SERS configuration, according to which the enhancement factor of the SERS signal is proportional to the square of that of the near field intensity at the pump frequency, we introduce more elaborate models which calculate the field scattered at the Raman-shifted frequency. For that purpose, the above mentioned near electric field calculations at the pump frequency are used in the non-linear polarization expressions corresponding to two models. On the one hand, a single molecule configuration is addressed by means of its classical electric dipole moment. On the other hand, a mono-layer of molecules is assumed to be given by a polarization layer discontinuous across the interface. In both cases, the rigorous integral scattering equations at the Raman-shifted frequency, the non-linear polarization acting as the inhomogeneous term, are then numerically solved. Finally, we will attempt to explore the SERS EM mechanism, and to corroborate the theoretical predictions, through experiments using rough surfaces of controlled statistics (Gaussian-correlated) as SERS metal substrates.

Surface Plasmon Polaritons in Light Scattering From a Random Rough Thin Metal Film on a Substrate

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By means of numerical simulation, we study the scattering of p-polarized light from, and its transmission through, a thin metal film on a glass substrate. This film on substrate system supports two surface plasmon polaritons with wavenumbers $k_1(\omega)$ and $k_2(\omega)$ at the frequency ω of the incident light. The illuminated surface of the film is a one-dimensional, randomly rough surface, whose generators are perpendicular to the plane of incidence, while the film/substrate interface is planar. The random roughness of the illuminated surface is characterized by a West-O'Donnell power spectrum that is nonzero only in a narrow range of wavenumbers $k_{\min} \lhd k |< k_{\max}$ that includes $k_1(\omega)$ and $k_2(\omega)$.

Our results show that the existence of two surface electromagnetic waves leads to the appearance of two satellite peaks in the angular dependence of the intensity of the incoherent component of the light scattered from the film at scattering angles θ_s given by $\sin\theta_s = -\sin\theta_0 \pm (c/\omega)(k_1(\omega) - k_2(\omega))$, where θ_0 is the angle of incidence of the light, in addition to the enhanced backscattering peak in the retroreflection direction $\theta_s = -\theta_0$. At the same time satellite peaks occur in the angular dependence of the intensity of the light transmitted incoherently through the film at angles of transmission θ_t given by $n_{glass}\sin\theta_t = -\sin\theta_0 \pm (c/\omega)(k_1(\omega) - k_2(\omega))$, where n_{glass} is the index of refraction of the glass substrate, in addition to the enhanced transmission peak in the antispecular direction $\theta_t = -\theta_0$.

These results are compared with those for a metal film on a glass substrate whose rough surface is characterized by a Gaussian power spectrum yielding the same rms height and rms slope as the West-O'Donnell power spectrum. They are also compared with results for the scattering of p-polarized light from a one-dimensional randomly rough surface of a semi-infinite metal characterized by the same West-O'Donnell power spectrum.

Second Harmonic Generation in the Scattering of Light from and its Transmission. Through a Random Metal Film in the Kretschmann ATR Geometry

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The earliest experimental studies of multiple-scattering effects, such as enhanced backscattering, in the second harmonic generation of light at a random metal surface were carried out in the Kretschmann attenuated total reflection (ATR) geometry [1]. In this geometry a thin metal film is deposited on the planar base of a dielectric prism, and its second interface, with air, is randomly rough. A p-polarized electromagnetic wave of frequency w is incident on the film through the prism, is scattered back into the prism from the film, and is transmitted through the film into air. The latter two processes occur both at frequency ω and at 2ω. No rigorous theory of second harmonic generation in this geometry exists at the present time. In this paper we present such a theory for the case of a one-dimensional random surface, that is based on the application of Green's second integral identity in the plane. It requires the solution of a system of four coupled inhomogeneous integral equations for the values of the magnetic field in the system and its normal derivative on each of the two interfaces, at w and at $2\ \omega$. This is done numerically by converting them into matrix equations. The electromagnetic boundary conditions used at each of the two interfaces at 2ω are those due to Agranovich and Darmanyan [2] applied to the free electron model [3]. Since the frequency w of the incident wave is in the infrared, we also explore the utility of impedance boundary conditions obtained recently for a metal film bounded by one planar and one randomly rough surface for simplifying the computationally intensive numerical work, and find a significant reduction in computer time by their use, with no significant loss of accuracy. Our computational results for the angular distribution of the intensity of the light scattered from, and transmitted through, a silver film at w and $2\ \omega$ are compared with experimental data.

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Speckle Correlations in the Second Harmonic Generation of Light in Reflection from a Randomly Rough Metal Surface

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Angular intensity correlation functions of light scattered from randomly rough surfaces is a growing field of interest. It was shown recently [1] that speckle correlations exhibit richer and more complex features when light is scattered from a randomly rough surface rather than in a disordered volume medium. Recently the interplay of disorder and optical nonlinearity has also attracted much attention. In particular, theoretical [2] and experimental [3] studies of the second harmonic generation of light in reflection from randomly rough metal surfaces have demonstrated that interference effects in multiple scattering produce interesting features in the angular distribution of the intensity of the generated light, which result from the multiple scattering of surface polaritons of both fundamental and second harmonic frequencies. In this work we study by perturbation theory and by a computer simulation approach the angular intensity correlation function of the second harmonic light scattered from a random metal surface characterized by a Gaussian power spectrum $g(|q|) = \pi^{1/2} a \exp(-q^2 a^2/4)$, as well as from a surface characterized by the West-O'Donnell power spectrum [4] given by $g(|q|) = (\pi/\Delta k)(\mathrm{rect}\,[(q-K_{sp}(\Omega))/\Delta k(\Omega)] + \mathrm{rect}\,[(q+K_{sp}(\Omega))/\Delta k(\Omega)])$, where $\Delta k(\Omega) = 2(\Omega/c)\sin\theta_{max}$, $K_{sp}(\Omega)$ is the wave number of surface polaritons of frequency Ω at a planar vacuum metal interface, Ω is the frequency of the fundamental ω or harmonic 2ω light, and rect denotes the rectangle function. We show that the short-range correlation function $C^{(1)}$ exhibit the memory and time-reversed memory effect peaks. The long-range correlation functions $C^{(1.5)}$ and $C^{(2)}$ display a rich variety of peaks associated with the excitation of surface polaritons of fundamental and harmonic frequencies.

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Detection of a small Defect on Top of Underneath a Rough Surface

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It is well known that the conductance of a mesoscopic disordered metal is extremely sensitive to the motion of a single impurity, or more generally, to any local change in the scattering potential that the electron wavefunction sees. There is also the analogous effect in the context of scattering from a randomly rough surface.

We report the detection of a defect from a randomly rough surface which shows that the far-field correlation function is sensitive to a small local change of the rough surface geometry, where the speckle spatial correlation is adopted rather than the sample ensemble average. The angular cross-correlation function of the far-field speckles scattered by one-dimensional random rough surfaces is measured, when a polarized beam of light is incident on the rough surface from vacuum, where one part of the surface used is a thin dielectric film deposited on a glass substrate and the other part is identical to the first one except for a localized defect on it.

Since the outgoing wavefront still memorizes the statistics of the rough surface geometry along the angular memory line, when a local change with different statistical characteristics is applied to the original surface, the new measured speckle correlation curve will have an elevated portion at the side lobe angular positions on the line perpendicular to the angular memory line. The ripples of the original side lobes become dull, and the correlation value is no longer reduced to zero.

We envision this property can be applied to inspection of a sample with defect by speckle mappings.

The authors wish to express their gratitude to the U.S. Army Research Office for their support under Grants DAAH04-94-G-0325 and DAAH04-96-1-0187.

Computer Simulation Studies of Speckle Correlations in the Light Scattered from Volume Disordered DielectricMedia

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Computer simulation studies are carried out of the speckle correlations in the light scattered from a volume disordered medium consisting of an arrayof dielectric spheres suspended in a homogeneous background medium. The spheres are identical, they are characterized by a positive, real, frequency-independent, dielectric constant ♏, and their radius is assumed to be smaller than the wavelength of the incident light. The homogeneous background medium is assumed to have a dielectric constant of unity. The scattering problem is treated in a scalar approximation. The randomness in the positions of the spheres is introduced by initially generating a simple cubic lattice of $20 \times 20 \times 20$ sites whose lattice constant is larger than the diameter of a sphere, and then centering a sphere at each lattice site with a probability *p*, or not with a probability *1-p*. For a fixed radius of the spheres their filling fraction can be varied by changing either the lattice constant of the underlying simple cubic lattice, or the probability *p*, or both. The scattering problem is reduced to the solution of a matrix problem whose dimension equals the number of spheres in the system, that is solved numerically. The angular intensity correlation function for the light scattered diffusely from the system is computed by averaging the results obtained for many randomly generated configurations of the suspension of spheres. These results are compared with recent results from perturbation theory which predict the existence of novel resonance peaks in the angular intensity correlations of speckle in the light scattered diffusely from three-dimensional volume disordered dielectric media. The effects on the angular intensity correlation function of resonances associated with the scattering of light from a single sphere are determined, as well as effects associated with the variation of the density of spheres in the background homogeneous medium. The angular intensity correlation function is computed for a variety of angles of incidence and scattering, and the contributions from the $C^{(1)}$, $C^{(2)}$, $C^{(3)}$ terms previously studied in the scattering of light from volume disordered media are determined. In addition, new features denoted by $C^{(10)}$ and $C^{(1.5)}$, which have previously been considered only in the speckle patterns of light scattered from randomly rough surfaces, are determined for the light scattered from our disordered volume system.

Signatures of Electromagnetic Surface Shape Resonances in Scattering of Pulsed Beams from Surface Defects

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Surface electromagnetic shape resonances are excitations with a finite lifetime, localized in the vicinity of an isolated defect on an otherwise planar surface. Despite a great deal of theoretical research [1,2] on their properties and role in various physical phenomena, explicit experimental evidence for the existence of these excitations is still lacking. Our recent paper [1] reveals that scattering of a monochromatic wave from a groove on a perfectly conducting surface, accompanied by local field enhancement inside the groove, does not always exhibit resonant features in the far field. The present work is the first theoretical study of the use of pulsed sources and their advantage over cw sources in detection of surface electromagnetic shape resonances in scattering experiments.

The idea of using pulsed beams in detection of resonant modes has been employed recently [3] in the theory of scattering of light from dielectric spheres. The physical properties of excitation and decay of Mie resonances in the spheres and of surface shape resonances prove to be quite similar. We consider an isolated groove of arbitrary shape on an otherwise planar, perfectly conducting surface, that supports one or more surface shape resonances. The system is illuminated by a Gaussian pulsed beam (localized in both space and time), whose duration is smaller than or comparable with the resonance lifetime. We calculate the local scattered intensity in the far zone by the formally exact method of moments with a parametrization technique [1] that allows treating reentrant surfaces. If the pulse spectrum lies well beyond the resonant frequency, the shape of the arriving pulse resembles that of the incident pulse. However, if the central frequency of the source spectrum is chosen at or near the resonant frequency, the arriving pulse has an exponential tail whose decay rate is equal to the decay rate of the resonance excited by the incident pulse. Thus, our theory should stimulate experimental use of pulsed sources in detection of surface electromagnetic shape resonances, and measuring their frequencies and lifetimes.

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Polarization Measurements of the Light Scattered by Isotropic Dielectric Randomly Rough Surfaces

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The scattering of electromagnetic waves by rough surfaces has been a subject of active research for several decades now. However, and despite its long history, the subject remains a challenging one for both, theoretical and experimental research. This interest derives partly from a need to study terrain characteristics of inaccessible sites and to detect and characterize deviations from optically smooth surfaces. Careful experimental work on scattering from rough surface can be used as a powerful tool for investigating surface and interface properties in regions not accessible to theoretical approaches. The rigorous numerical techniques widely reported in the literature have proved very useful for the validation of the theoretical approaches to the problem of the scattering by one-dimensional surfaces, but their two-dimensinal counterparts are still limited in their capabilities.

In this presentation, we will report on an experimental study of scattering by characterized isotropic dielectric surfaces, whose profiles constitute good approximations to Gaussian random processes with Gaussian correlation functions. The surfaces are fabricated in photoresist by repeated exposure to laser speckle patterns[1]. In order to reduce the influence of stray light and unwanted reflections, the glass substrates employed consist of thick plates of absorbing glass whose refractive index is close to that of the photoresist. In this situation only the air-photoresist interface is believed to be important, and the results correspond to those of a two media system. In previous work[2], we have reported in-plane angular scattering measurements that display interesting backscattering and polarization effects. We now report on a more extensive set of measurements of the polarization properties in, and out of the plane of incidence.

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Effect of the Long-Scale Roughness on the Light Scattering from Slightly Rough Dielectric Layers

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Scattering of waves from slightly rough, thin, dielectric layers is a classic problem with a long and prestigious history. It still remains topical due to many important applications (characterization of optical coverings, planar wave guides, remote sensing, etc). However, in spite of the seeming simplicity of the problem and the vast literature covering the topic, there exists no proper theoretical description and clear physical understanding of some of the experimental features. Moreover, in some cases, the scattered intensity distribution calculated via direct solution of Maxwell's equations by standard perturbation theory differs drastically from that measured experimentally, even when the roughness parameters are well within the conventional region of validity of perturbation theory.

Our experiments were carried out using 2 mm diameter beams from a He-Ne and/or Argon ion lasers, and two types of samples: a) microscope cover slip glass plates of 150 μm thickness, coated on one side by a 200 nm thick, reflecting Al film, and b) Fabry-Perot plates of 0.5 mm thickness. The only difference between samples a) and b) was that while the Fabry-Perot plates had only short scale roughness (SSR) with rms height h, the roughness spectrum of the ordinary glass plates contained (along with SSR of the same size) also a long-scale component (LSR) with rms height σ. LSR was a consequence of deviations of the glass surface from perfect planarity varying from 0.01 μm to 0.1 μm on the horizontal scale of order 1 mm. The intensity distribution of light scattered from such plates consisted of speckles that arranged themselves into concentric interference rings centred around the normal to the layer.

We show that this is precisely the LSR that determines the dependence of the ring positions on the angles of incidence and scattering. Scattering diagram from a slightly rough dielectric film is extremely sensitive to the long scale corrugations of the interface. Even very small ($\sigma \sim h << \lambda$) smooth deviations of the surface from a perfect plane, that practically do not effect the total rms roughness, change drastically the interference pattern.

Conventional perturbation theory is shown to be invalid in cases where interference phenomena in the scattering are of importance. A model is proposed that enables calculation of the scattering diagram in the presence of both LSR and SSR. It describes quantitatively the measured angular intensity distributions.

Session B01
Monday, July 13, PM 13:40-17:20
Room G/H
Mathematical Methods for inverse scattering problems

Organisers : Ch. Pichot, S. Caorsi
Chairs : A.K. Louis, P.C. Sabatier

Inverse scattering problems and the variational principles

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Exact and approximate inverse scattering procedures are used for systematic and efficient estimation of material properties, such as dielectric constants, from the scattering data. Exact methods for solving such profile inversions in one-dimension are well known. However, these methods appear to be computationally intensive, sensitive to the range of the available data, and they are not easily extendable to multi-dimensional inverse problems.

On the other hand, there exist many elegant and computationally efficient approximate inversion methods based on Born approximation. Such methods are usually stable and are easily applicable not only to one-dimensional profile reconstruction, but also to multi-dimensional inverse problems. However, it should be noted that the range of applicability of procedures based on Born approximation are limited to weak scatterers.

This limitation is due to the fact that in Born approximation, one assumes that the field inside the scattering region is the same as the incident field. In order to remedy this shortcoming, for the profile reconstruction of one-dimensional dielectric media from the reflection data of a TEM-polarized plane wave normally incident on a dielectric slab, a new method based Schwinger variational principle is presented, where a better approximation for the field inside the scatterer is used for the inversion procedure.
It is remarkable that profile reconstruction using this method is not only more accurate than Born inversion, but also its numerical implementation is not computationally too intensive.
Also numerical experimentations, using synthetic data with added noise indicate that the proposed inversion procedure also retains the very desirable property of the Born approximation regarding the stability of the inversion. We study the mathematical properties of the proposed method and present further insight into the nature of the Schwinger variational solution and the associated inversion procedure.
Also we systematically develop a sequence of more accurate extensions of the Born inversion method based on higher order variational solutions.

An interesting by product of such extensions is the ability to develop procedures to estimate the accuracy of the reconstructed profile by comparing the reconstructed profiles from higher order inversion methods, developed in this study. An exactly solvable analytical example is used to illustrate how the proposed inversion procedures are to be applied for recovering the dielectric constant from the input data.

An Approach to the Problem of Diffraction Tomography Using a T-Operator Equation

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In diffraction tomography, intensive researches have been devoted to derive methods to give a high-resolutive image for a strong scattering object. Since the object function (internal characteristics) relates nonlinearly to the scattered wave in the inverse problem, optimizing techniques are often used, where the direct scattering problem is solved repeatedly. The solution may be in fatal error if the optimization process is trapped at local minimum points. The keys to solve the problem are how to develop a fast algorithm of the direct scattering problem and how to escape from local minimum points, but have not been opened satisfactorily. Such a situation is derived from the analysis of the conventional integral equation for the scattered wave, equation which includes the object function within the kernel, and may be changed if another equation forms a basis for the inverse problem.

We propose a novel inverse method using a T-operator. The T-operator is defined as an operator which transforms the incident wave to the internal current distribution, and satisfies a linear equation. The operator equation shows that the object function can be determined from the T-operator through linear calculation. It may be practically impossible to determine the T-operator completely from the measured scattered-waves because we can use band limited incident waves and measure the scattered waves within some region out of the object. However, if the T-operator is approximately obtained from limited measurements of scattered waves, it is easy to calculate an approximate object function from the approximate operator.

In order to make clear the characteristics of our method, we deal with the case that single-frequency plane waves illuminate a simple object and the scattered waves are measured in a far region. The numerical examination will be done and the comparison with other methods will be presented.

Reconstruction of a Penetrable Object with the Aid of Approximate Inverse Via Singular Value Decomposition of the Scattering Operator

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The purpose is to compute numerically the potential $\mathbf{O}$ in the Helmholtz equation $(\Delta + k^2)u = -k^2\mathbf{O}u$ from plane wave irradiation at a fixed frequency. It is assumed that the field can be measured outside the support of the unknown potential for finitely many incident waves. Based on the idea of *approximate inverse* for linear and some nonlinear problems introduced by Louis (see [Lo 97]) a new approach for solving the above inverse scattering problem will be presented. Starting with the Lippmann-Schwinger integral equation the problem of determining the potential is to solve a nonlinear integral equation. Introducing the so called equivalent source $\phi(x) := \mathbf{O}(x)u(x)$ it is possible to consider the following "implicitly nonlinear " operator equation

$$(S\phi)(x) = u_s(x) \text{ with } (S\phi)(x) := -k^2 \int_\Omega G(k|x-y|)\phi(y)dy$$

for given data u_s and Green's function G. The application of the approximate inverse consists in precomputing the *reconstruction kernel* ψ as solution of the equation $S^*\psi_\gamma = e_\gamma$ for a suitable mollifier e_γ. With the above representation of the scattering operator S one has the possibility to compute the singular value decomposition of S in order to determine the reconstruction kernel. The equivalent source is then evaluated as a scalar product of the kernel ψ with the scattered field u_s (for measured or simulated data). Through this technique the scattered field is mapped to a regularized approximation for the unknown potential $\mathbf{O}$ by dividing the equivalent source ϕ by the total field u.

The approximation for the potential $\mathbf{O}$ is achieved without any explicitly linearization and solving the direct problem. Furthermore the solution operator can be precomputed independently of the data (near or far-field data). The application of this new approach is not restricted on weakly scattering potentials, it is also valid for strongly scattering ones. Some invariance properties of the scattering operator could be used to reduce the computational efforts.

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Optimized Sources in Inverse Electromagnetic Problem

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The talk deals with the inverse electromagnetic problem for lossy medium. For low frequency currents, this problem is usually reduced to an inverse problem for a parabolic equation, where the wavy character of the field is neglected in comparison with diffusion effects. For high frequency excitations, the wave equation is exploited as an approximation, hence neglecting the diffusion of the field associated with conducting medium. We develop an alternative effective approach to the inversion problem that can be used for the intermediate range of frequencies, when both approximations fail. The approach is based on a special representation of the system of Maxwell's equations and optimal choice of the excitation patterns.

When displacements currents in a lossy medium cannot be neglected, we formulate the inverse problem for the whole system of Maxwell's equations in frequency domain. Having doubled the number of equations, we represent the Maxwell's system using a real, symmetric, self-adjoint operator. We consider the problem of increasing the resolution of the inverse electromagnetic problem by optimizing the intensity and the phase of an array of electromagnetic sources. Data due to this optimal source are used then to obtain a solution of the inverse problem by a gradient technique.

The first problem is to design an optimal source, which concentrates the current flux to the region of inclusion. The solution of this problem is given by the first eigenfunctions of a generalized eigenvalue problem. These eigenfunctions provide a basis for a natural parameterization of the space of solutions of the inverse problem, which is used for constructing an effective algorithm for electromagnetic inversion. The method of solution of the inverse problem is based on a gradient technique with eliminating directions orthogonal to the linearized increment of the solution. The information about these directions is deduced from the analysis of the eigenvalues. We used a similar approach to inversion scheme in our previous work [1] for conductivity problem with direct current measurements.

A particular example of such a problem in intermediate range of frequencies is interpretation of coupling in induced polarization problem in geophysics. Effectiveness of the method is demonstrated on a numerical example.

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Inverse Scattering and Design of Semiconductor Heterostructures

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A method is proposed for designing semiconductors heterostructures having a prescribed energy dependence of the transmittance.The key idea is using inverse scattering theory in order to achieve this design. However, the relevant problem is not the classical one but a problem where the potential must goto different finite limits at + and - infinity and have a prescribed upper bound between. As a consequence, for instance, zero reflectance cannot be reproduced by means of an acceptable structure but only reflectance having a (very) small value in a wide energy range.

Inverse Scattering Theory Applications to Photonic Devices

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The traditional procedure to synthesize optical devices is to start from device parameters that yields transmission characteristics that is close to the required characteristics of the device and iteratively change the device parameters until the required transmission characteristics of the device is achieved. This procedure is time consuming as it is an iterative procedure and also the initial value of the device parameters are crucial as an inappropriate assumption can lead to diverging solution. On the contrary, techniques based on inverse scattering theory can yield design parameters of the device without the need for initial assumption of the device parameters and the procedure is non-iterative.

An analytic technique based on Gelfand-Levitan-Marchenko integral formulation and a numerical technique that extends the capability of the inverse techniques to provide solution for a generalized class of scattering characteristics that have been developed by us will be discussed. Design of a class of devices such as intra-chip optical interconnects, and all-optical logic devices based on these techniques will also be discussed.

An efficient guiding structure based on inverse scattering theory has been designed for optical amplifier application. The optical amplifier application requires a guiding medium that has same propagation constant for the signal and the pump. The inverse scattering theory for this involves the reconstruction energy-dependent potentials or wavelength dependent refractive indices which is much different from the cases that have been discussed earlier.

The extension of the inverse scattering technique developed for planar optical waveguides have been extended to cylindrical structures. This is not straight forward, rather very cumbersome. However, we have succeeded in developing inverse scattering theory for the design of multimode cylindrical fiber with same propagation constant for all propagating modes and the design of single mode fiber that has the same propagation constant for more than one wavelength. These structures will find application in image and high data transmission. Our talk will include discussion of these cases.

Topological Shape Optimization of Radio-Electrical Structures

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Classical shape optimization tools use an initial guess defined by the user and the final shape has the same topology as the initial one. The aim of topological optimization is to find an optimal shape even with a poor information a priori about the optimal structure.

Most of the important contributions in this field are based on the optimization of material properties. However, the domain of application of this approach is quite restricted.

For this reason global optimization techniques, like genetic algorithms and simulated annealing, are used in order to solve more general problems. Unfortunately, those methods are very slow.

The notion of topological sensitivity gives an interesting alternative:
- its application domain is very large,
- using 'gradient' information, we can build fast algorithms.

The topological sensitivity is a function defined on the computation domain giving an information about the opportunity to create a small hole at each point of the domain. This function is very easy to compute.

If $J(\Omega)$ is a radio-electrical criterion of the computation domain Ω then

$$J(\Omega - B(x, \varepsilon)) - J(\Omega) = f(\varepsilon)\, g(E_0(x), P_0(x))$$

where
* $B(x, \varepsilon)$ is a small metallic ball located at point x,
* P_0 is the well known adjoint state related to J,
* f and g are very simple functions..

This method was applied to a coupler optimization in order to obtain a given S matrix. Three optimal solutions was obtained after only one, two and seven finite elements analysis.

Global ALgorithm with Local Optimization (GALLOP) : A New Approach to Antenna Array Optimization.

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Antenna array optimization problems are very sensitive to local optima. Classicalantenna array optimization tools are then often victims of convergencetroubles. To avoid this kind of disadvantages, a new Global ALgorithm withLocal OPtimization (GALLOP) [1] is introduced.

GALLOP integrates in a natural way some basic concepts from simulatedannealing, genetic algorithms and local optimization method : a globallinear search is performed in each descent direction. GALLOP works with apopulation of points. To avoid clustering effects, a penalization term is added to the selection function,taking into account the distance between one point of the population and theothers. The penalization coefficient T, called temperature, decreases with the iterations like in simulatedannealing algorithms. When T is large, the algorithmexplores the space and when T is low, it converges locally. With this selection function, each point ofthe population converges to a different minimum. The local convergence ofGALLOP to different minima has been proved [2]. Moreover with, for example, three points in thepopulation, the algorithm may provide a very large number of local minima :we have just to store all the rejected local minima.

Obtaining several different minima allows to choose the most robust one with respect to random error on excitationcoefficients or radiating element failure. The selection of the most robustsolution is realized by means of classical statistical analysis tools, overall the local minima found by GALLOP. The obtained results on this problem confirm the efficiency of this newoptimization method.

References

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A Point-Source Method in Inverse Electromagnetic Scattering

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We present a *point-source method* PSM to solve inverse electromagnetic obstacle scattering problems. The PSM gives a new and explicit procedure how to compute locally from the far field pattern E_∞ an approximation for the total electric field E near the unknown obstacle. The PSM then searches for the boundary of the obstacle as a zero-curve of $p \cdot E$ with a vector field p tangential to the unknown domain. We present the mathematical foundation for the method in two and three dimensions. Convergence properties of the method are investigated and numerical examples for the two-dimensional cases are presented.

R-Functions Method (RFM) for Direct and Inverse Boundary Value Problems with Complex Domains in the Diffraction Theory

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With R-functions method in the theory diffraction for complex domain appears the possibility of creating a constructive mathematical tool, which incorporates the capabilities of classical continuous analysis and logic algebra. This allows one to overcome the main obstacle which hinders the use of variational methods when solving boundary value problems in domains of complex shape with complex boundary conditions, this obstacle being connected with the construction of so-called coordinate sequences. In contrast to widely used methods of the network type (finite difference, finite and boundary elements), in the R-functions method all the geometric information present in the boundary value problem statement is reduced to analytical form, which allows one to search for a solutions in the form of formulae called solution structures containing some indefinite functional components. A method of constructing solution structures satisfying the required conditions of completeness has been developed. The structural formulae include the left-hand sides of the normalized equations of the boundaries of the domains or their regions being considered, thus allowing one to change the solution structure expeditiously when changing the geometric shape. Given in the work is a definition of the basis class of R-functions, solution with their help of the inverse problem of analytical geometry.

Thus, the main idea of the RFM consists in two steps. In the first one, which is of an analytical nature, the general solution of the problem is generated in the form of a so-called "general structure of the solution" (GSS) which strictly satisfies all the prescribed boundary conditions and contains some undetermined functions. In the second step these functions are found by means of any known numerical method in order to satisfy the governing differential equation or to minimize a corresponding functional.

This work focused on direct and inverse scattering problems of determining the complex shape of scattering obstacle from the knowledge of the far field pattern of scattering field. The cases of a perfectly conducting scatterer, of superconducting surface impedance and of a penetrable obstacle are investigated. Examples of identification and synthesis problem are given.

We suggested general algorithms of numerical solving of the direct and inverse problems of electrodynamics and elastic waves are considered.

Session C01
Monday, July 13, PM 13:40-17:20
Room I
Time Domain Methods I

Chairs : R. Beyer, A. Reineix

FDTD Analysis of the Mutual Coupling Between Dielectric Resonator Antennas

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Dielectric resonator antennas (DRA's) are preferable to the microstrip patch antennas (MPA's) for some millimeter wave applications because conductor losses and surface wave are avoided in the radiating side of the antenna and a wide band can be easily obtained. Furthermore, at millimeter wave frequency the dimensions of the dielectric resonator became small and thus suitable to be integrated in planar MIC structures.

The design of a DRA-based array represents a very involved task due to the lack of simple rigorous models of DRA resonance modes and radiative coupling between the adjacent elements of the array.

A Finite Difference Time Domain (FDTD) approach is here proposed in order to analyse the coupling phenomena arising in an array which employs aperture coupled rectangular DRA's as radiating elements. The analysis is carried out by referring to a couple of DRA's fed by a microstrip slot combination, as depicted in Fig 1. The S_{12} scattering parameter of the structure,which models the coupling between the two DRA is determined taking advantage of its geometrical symmetry. Two separate FDTD runs are therefore required to calculate the even and odd mode S_{11} parameters of one half of the structure, in presence of a magnetic or an electric wall respectively. The S_{12} parameter is then determined in modulus and phase by resorting to the superposition principle.

This procedure is computationally more efficient than that based on the analysis of the complete structure.The simulation results show that the free space propagation constant can't be used in order to determine the electrical distance between the phase centres of the two DRA's. This result confirms was formerly evidenced by G.D. Loos et alii (ANTEM 94) by measuring the locations of the radiation pattern nulls of a four element array.

A wideband analysis of the above mentioned coupling mechanism is then presented.
Numerical results show the dependence of the S_{11} and S_{12} parameters of the two port symmetrical antenna versus the distance between the two DRA phase centres. These results are particularly useful for the accurate design and analysis of more complex DRA's based array structure.

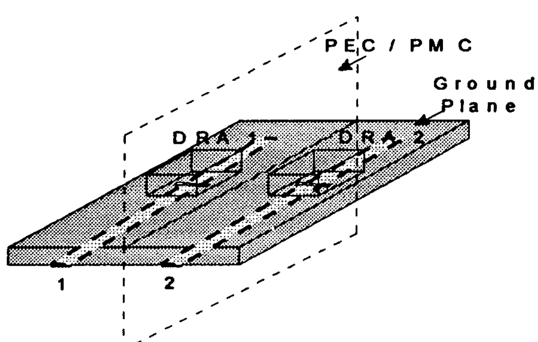

Fig. 1

The Holland Model for the Thin Wire Simulation Revisited

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The study of complex radiating structures has provided the development of various thin wires simulations in electromagnetism.

The most popular is based on the so called Holland model.

This model is designed for the simulation of thin wires in FDTD codes. Its great interest is to allow the use of a discretization step independent of the diameter of the wire.

However, this FDTD technique suffers from geometrical and stability limitations : the simulated wires are constrained to be parallel to the mesh axis (``non parallel axes" long time experiments show instability at large time) and the precision of the method decreases with the diameter of the wire.
In this talk, we get on to different points concerning this method and propose some improvements. We show that the Holland model can be regarded as a discretized form of a set of continuous equations describing the wire-field interaction.

This provides a natural mean to generalize the model to arbitrarily shaped wires.

We also discuss stability. At first, we derive an approximate stability criterion for the classical Holland scheme that provides a good estimate of its actual value. Then, we propose a modification of the time discretization that leads to a stable scheme under the usual CFL condition c Delta t/sqrt{3} <=1.

We emphasize that this stability condition does not depend on the dimension of the wire.

Finally, new formula for the computation of the numerical wire inductance are given. They are derived from the analytical calculation of the discrete solution of the diffraction by a wire of infinite lenght.

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Efficient Analysis of Strongly Modulated Periodic Structures Using the FD-TD Method

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Throughout the development of optoelectronic devices, periodic structures have played a key role, like in periodically segmented waveguides, tunable optical filters, multiplexer and demultiplexer components. In order to calculate precisely the characteristics of DFB lasers and recently in photonic crystels efficient numerical tools are necessary.

The Finite-Difference Time-Domain (FD-TD) method takes into account all the properties of electromagnetic wave propagation including reflections and transients. The main advantage of the FD-TD method is its ability to handle arbitrary structures so even the influence of fabricational tolerances can be easily implemented. Furthermore, the FD-TD algorithm is well-suited for distributed-memory and shared-memory multiprocessors.

We verify the accuracy of the FD-TD algorithm by comparing its results on periodic structures with theoretical results (e.g.: Transfer Matrix Method). We investigate the characteristics of strongly modulated periodic structures including photonic cristals. The following phenomena have to be considered and to be compared: absorption, arbitrary scattering phenomena, and numerical phenomena. We demonstrate the influence of multiple phase shifts and we describe the consequences of positioning errors with respect to the practical application of the relevant structures.

Additionally, we investigate the possibility to reduce the length of periodic structures by the increase of the modulation index. In contrast to the previous applied formalisms (e.g.: Floquet-Bloch formalism) especially the FD-TD method permits an efficient and exact analysis of the wave propagation in strongly modulated periodic structures.

FD-TD Analysis of Electromagnetic Radiation Through Slots in a PC Metallic Enclosure

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The radiation from a module-on-backplane structure has been investigated in literature [1] where it has been found that the radiation was enhanced when the modules configuration was partially placed within a metallic enclosure. Another source of radiation is the heatsink where its radiation characteristics is very similar to a microstrip antenna when the metallic enclosure is neglected [2]. The effect of the narrow slots in the metallic enclosure, which are usually used for ventilation, has not been investigated. In this case, the induced currents by the cavity will affect the field distribution and radiation characteristics [3].

In this paper, a three dimensional FDTD model which is complemented with PML layers is used to analyze the electromagnetic radiation from a module-on-backplane through a slot. The geometry of the problem consists of a rectangular metallic box that contains one or more slots located in the front side as shown in Figure (1). The source of excitation is taken as a Gaussian pulse to cover a wide frequency range. The analysis will include the distribution of the fields inside and outside the enclosure as well as at the slot. Also, the effect of the number of slots, slot size and the number of modules on radiation characteristics will be examined.

* The authors acknowledge the support of King Fahd University of Petroleum & Minerals.

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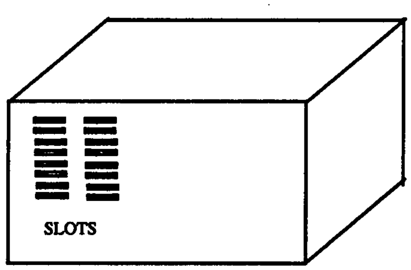

Figure 1 PC enclosure with ventilation slots.

Time Frequency Domain Semi-Inversion Technique for One Class of Waveguide Discontinuities

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In classic functional analyses and in the theory of singular integral equations the partial inversion of operator of a problem had been successfully used for rather large body of problems and proved itself to be fruitful and efficient.

The present paper covers the results of consistent implementation of the idea of operator semi-inversion for analytical regularization of electromagnetic and acoustic boundary value and initial value problems. The class of model problems considered comprises resonant type discontinuities in circular and coaxial wave guiding lines.The main goal of regularization is to achieve equivalent efficient and robust formulation of the problem, that can be used as a basis for a reliable time-efficient numerical algorithm, bringing results with any required accuracy. The algorithm, that is intended to provide full wave qualitative and quantitative study of time-space field transformations when the resonant wave scattering phenomenon may arise.

Within the framework of unified technique the diffraction (frequency domain), spectral (eigen quasi stationary modes of field in the domain of non physical values of frequency parameter) and non stationary (time domain) problems have been considered. The variant of partial inversion applied herein relies on the analytical solution in closed explicit form of the key problem: scattering of waveguide waves by coaxial bifurcation in circular waveguide. The construction of algorithms for resonant discontinuities (resonant volume bounded by short-circuit planes, inserted in various transverse partial regions, creating resonator of finite length, loaded on infinite coaxial or circular waveguides- the channels for energy radiation), is based on association of semi-inversion and generalized matrix technique (diffraction and spectral problems) and on technique of transform operators of non stationary signal evolutionary basis (time domain) [1].The principal results, that are to be discussed in the report are following.

Frequency domain. Inhomogeneous (diffraction) and homogeneous (spectral) boundary value problems are reduced by means of semi inversion technique to matrix equations of Fredholm type with compact in diffraction problem and trace class operator in spectral problem (in space of Fourier coefficients of field) with exponentially convergent truncation procedure of numerical solution of matrix equations.

Time domain. The initial boundary value problem is reduced to the Volterra integral equation of the second kind with matrix kernel of the property, enabling to solve numerically Volterra equation, without inversion of matrix kernel in every step of integration, that considerably increase efficiency of numerical algorithm.

Numerical algorithms had been thoroughly tested and cross-checked. The characteristic cases studied showed algorithms to be a powerful and reliable tool for basic and applied investigation of physical features and peculiarities of time-space field transformations in resonant structures that are of practical interest in many applications in modern microwave engineering and scientific devices design [2].

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Reducing the Number of Field Simulations for Optimizing passive MMIC's

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A new optimization method for passive microwave structures on the basis of an FDTD-field simulator is presented. The field simulation method that is used in this article is the FDTD-method (finite difference time domain) [1,2]. For the FDTD-method the Maxwell's equations are solved by the leap-frog-algorithm.

The method is reducing the number of time consuming numerical FDTD-field simulations in the automatic optimization process. The parameter interval must be sampled by an adequate number of field simulations. The results of a minimized number of field simulations are projected on IIR filter pairs (transmission/reflection) [3]. The pole and zero positions of the IIR filter pairs are parameter vector dependent. The pole and zero positions of the z-domain transfer functions are interpolated using cubic spline functions.

If all pole and zero positions in z-domain are known, no further time consuming field simulations inside the parameter interval are needed for the optimization procedure. For the majority of the structures to be optimized, the optimum behavior can directly be determined from the z-domain chart. For these structures no further optimizing algorithms are needed.

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Broadband Model of Anechoic Chamber using Debye's Equations for the FDTD

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Anechoic chambers provide an attractive alternative to Open Area Test Site (OATS) in frequency range 30 to 1,000 MHz for obvious weather and convenience reasons. However they have to meet new standards which become more and more severe. Correlation of measurements in a chamber to measurements on an OATS is not always possible. A better understanding of field propagation mechanisms can be obtained using numerical analysis [1].

These methods are often time consuming and involve important computational resources. To avoid the time consuming full wave analysis of the pyramidal absorbers, we used an equivalent layered model of absorbing materials. This model uses the homogenisation method and is valid as long as the wavelength remains longer than the size of the absorbers under consideration. Absorbers are replaced with equivalent anisotropic layers whose properties are found according to [2]. This model is well suited to FDTD simulations. The number of necessary layers has been studied in [1]. This criterion is combined with numerical dispersivity criteria of the FDTD to derive the size of an elementary cell.

Since the absorbers are made of strongly dispersive materials, chamber models are different for every frequency. Therefore a frequency analysis of the chamber's performance requires simulations to be run separately at each frequency of interest. This constitutes a very high computational burden. Moreover a continuous description of the chamber's behaviour according to frequency is impossible.

To alleviate this computational weight and to permit a continuous description of the chamber according to frequency, we utilised Debye's model of dispersivity in the FDTD. The complex coefficient of permittivity is a function of three parameters : e_S, $e_{¥}$ and t. These parameters are optimised to accurately describe the evolution of the three spatial components of the anisotropic permittivity in the layers. We thus obtained a broadband model of anechoic chamber.

This model has been applied to the semi anechoic chamber of the CNET. The frequency range of validity of the obtained broadband model is 50 to 400 MHz. A pulse excitation is modelled in the chamber and the Spectral Power Density (SPD) is calculated in different points in the chamber. These results are compared with non dispersive models valid for a single frequency. The results for these frequencies show agreement within 10 %.

We show that it is possible to retrieve valid information on a broad band of frequencies in a single run entailing a tremendous lessening of computational load.

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Analysis of UWB Scattering from Dielectric Objects Buried in a Lossy Layered Ground using FDTD and TLM

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In this paper we investigate the use of the finite difference time domain (FDTD) and the Transmission Line Matrix (TLM) methods for analyzing the time domain ultra-wideband (UWB) scattering response from a dielectric object buried in a lossy layered ground. The main purpose of this research is to investigate the scattering features available in such a response which could be used to detect/identify buried land-mines. It is important that a numerical analysis of the problem not introduce any computational artifacts into the scattered signal which may obscure salient and sometimes subtle scattering features which are important to the detection/identification problem. Both the FDTD and the TLM methods have been used in the past for such a purpose (see for example [1] and [2]). In [1] the problem analysed was a scaled experimental model which was enclosed in a conducting box. The main purpose was to validate the numerical FDTD results using experimental results. The FDTD mesh was terminated in PEC (perfect electric conductor) boundary conditions and the effect of using ABC's (absorbing boundary conditions) to truncate the mesh was not encountered. In [2] the TLM method was applied to quantify the interaction of an electrically short dipole source and various conducting objects buried in the ground. The quantification was limited to the change in dipole input impedance caused by the presence of the object and lossy ground. For reliable identification, more information such as that contained in the UWB response is required.

In order to investigate a realistic UWB ground penetrating radar (GPR) application we must first evaluate the effect of ABC's when they are used to truncate a mesh in which an infinite lossy layered ground is being modelled. We first compare the FDTD and TLM solutions of an electric dipole above a lossy layered ground (with no buried object) to a semi-analytic frequency domain solution using the transfer matrix formulation. The comparison includes the use of the various ABC's, such as the perfectly matched layer (PML) and Mur's first and second order ABC's, found in the literature. The effect of implementing dispersive ground layers is also studied for its effect on the performance of the ABC's.

Next we calculate, using FDTD and TLM, the time domain scattering from various dielectric objects with dimensions and material properties chosen to represent typical land-mines. The scattered signal is investigated for features which can be used for detection/identification of the land-mines. A complete system, including UWB transmitting and receiving antennas, is analyzed. The effect of the antennas on the scattering features of the targets is investigated.

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Electromagnetic Diffraction Computing by FDTD and Fictitious Domain Method

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The popular FDTD method suffers a lack of precision due to the staircase approximation of the geometry. The 'fictious domain method' is introduced to localy modify the classical scheme and correct the electromagnetic fields near the obstacle. The solution of the exterior obstacle problem is extended to the interior one and the boundary condition is verified weakly and appears as a constraint of the original problem. A corresponding fictitious current is used as a Lagrange multiplicator of an associated Lagrangian formulation.
Theory is being intensively studied (existence of the current is prooved by an Inf-Sup condition and practical using of a compatibility relation between surfacic and volumic mesh). An industrial software has been developed, based on a Maxwell formulation adapted to the classical FDTD method, including parallelization capabilities and results for perfectly conducting 3D targets spanning dozens of wavelenghs are presented : for the Radar Cross Section of a sphere, better results are obtained by a fictious domain method rather than a classical FDTD approach.

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Study of coplanar fed antennas using the FDTD method

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This paper presents the analysis of innovative coplanar fed planar antennas with the aid of a simulation tool based on the Finite Difference Time Domain method (FDTD). The antennas presented are especially suited for mobile communication purposes and identification systems due to their small sizes and rather omni-directional radiation pattern (for most radiation directions). Two different types of antennas will be presented: a printed slot antenna at 2.5 GHz, and a printed inverted F antenna at 5.8 GHz, both coplanar fed. The FDTD-tool applied uses a non-uniform discretisation grid that makes it possible to model small structures (compared to the wavelength) in combination with large structures more accurately. The FDTD simulations are not only used for the analysis and design of the antennas but also for examining the influence of the coaxial connector required for measurements. The FDTD-tool proves to be a valuable tool for the investigation of such problems because it is possible to model the antenna and the connector quite accurately. In this way, it is possible to explain discrepancies between the measurements performed with the connector, and simulations done without including the connector in the model. Only by including the connector into the FDTD-model, it is possible to explain these discrepancies. Both measurement and simulation results will be presented for the two antenna types mentioned earlier. Similarities and differences between them, and also the influence of the connector on the antenna characteristics will be discussed.

Session D01
Monday, July 13, PM 13:40-15:00
Room 120
Time Domain Methods II

Chairs : J. Wiart, J. Lo Vetri

Propagation Characteristics in Waveguides Composed of Dielectric Disks

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Introduction

The wave guidance in dielectric waveguides with a periodic structure has been the subject of theoretical and experimental studies. In this article the waveguide comprising many dielectric disks arranged at equal spaces is analyzed by using the FD-TD method. The wave propagating along the line of the separate disks is modulated spatially. The modulation indices is so large that the phenomena proper to periodic structure occur radically.

Structure

Figure 1 shows the structure considered here. Many dielectric disks with a radius $r=a$ are spaced equally on a straight line. HE_{11}-type wave is fed through a uniform rod dielectric waveguide into the periodic structure along the z axis. The FD-TD method in a cylindrical coordinate system is applied to this problem. Since the azimuthal field variation of the incident wave is known analytically and the structure of Fig. 1 is axially symmetric, the dependency on thefdirection can be eliminated from the fundamental relations of FD-TD. The one side of the two-dimensional FD-TD grid region coincides with the z axis, and the other three sides are surrounded by PMLs.

Propagation characteristics

It is desirable to feed the wave energy of the uniform waveguide into the line of disks efficiently. The radius should be chosen properly depending on the size of disks and the space s. The uniform waveguide are connected to the line of disks by a transducer with taper and periodic shape. The conversion loss of wave energy can be lowered under 1 percent. The converted wave is propagated through the line of disks without attenuation in a frequency region. The line of disks operates as a waveguide.

Figure 2 shows the field distribution in the waveguide with w=0.35a, s=0.35a, and ϵ_r=2.0 for ka=3.6. The shape of the envelope varies like a standing wave with respect to z direction and the relatively long period depends on the frequency. The field varies with a period of 2p and the points where the instantaneous value becomes maximum do not depend on time and the frequency. These features may be applied to discriminate a frequency of a wave in the waveguide. The attenuation quantity, the spatial spectrum, and the radiation characteristics in the Bragg reflection and the leaky wave regions will be shown in presentation.

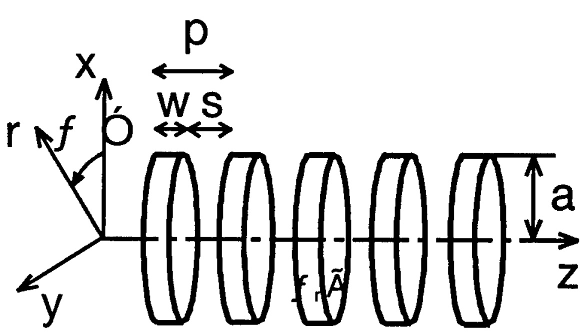

Fig. 1 Waveguide composed of dielectric disks

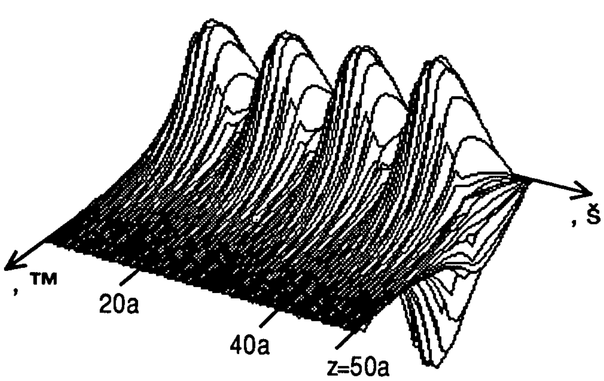

Fig. 2 : Field distribution

CRETE : A Finite Element Time Domain Code Applied in Industrial Context

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In the conception of microwave devices, like antennas or circuits, shortening conception time implies using numerical tools. Very often it is necessary to be able to analyze in a broad band of frequencies. Temporal tools are well suited to achieve this target.

Several methods can be used to calculate the temporal electromagnetic comportment of the structures. First of them is Finite Difference in Time Domain. This method is very mature because it has been extensively applied by many users. The major problem in industrial situation is that the meshing is not yet automatic. Very often we are led to simplify the geometry of the structure to be able to have a structured mesh. Another one is the Integral Equations in Time Domain. This method is attractive because meshing is reduced to interfaces. More, boundary conditions are normally taken into account by Green's functions. This method is not so mature than FDTD and all the problems of stability are difficult to be controlled.

In this paper we will present Finite Element in Time Domain used in industrial context. The major advantages are the ease of meshing because many commercial tools exist, the well controlled stability of this method, the large diversity of devices that can be studied by this method.

The first point presented is the form for Maxwell equations that allow to take into account lossy or anisotropic materials and the variationnal formulation that led us to Finite Element formulation.

The second point is the technique used to close the calculus domain. We have developed a method which is a variation of the PML method used in FDTD. This is a natural way to take into account unbounded media.

The third point is the integration of many kind of feeding systems in the code.

Several examples including antennas, multiport structures, circuits .... that have been studied by this code will be presented.

A Numerical Method for Electromagnetic Pulse Interaction with Large thin Wire Structure

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To simulate the interaction of an electromagnetic pulse with a wire structure, the time domain integral equation derived from Maxwell's equations can be written as :

$$(1)\begin{cases} \dfrac{\partial \vec{A}(r,t)}{\partial t} + \vec{\nabla}\Phi(r,t) = -\vec{E}(r,t) \\ \vec{A}(r,t) = \dfrac{\mu_0}{4\pi}\displaystyle\int_\Omega \dfrac{\vec{J}(r',t')}{R(r,r')}dr' \\ \Phi(r,t) = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int_\Omega \dfrac{\rho(r',t')}{R(r,r')}dr' \\ \dfrac{\partial \rho(r,t)}{\partial t} + Div\vec{J}(r,t) = 0 \end{cases}$$

where : A(r,t) is the vector potential
TTTbo the scalar potential
E(r,t) the electric field

TTTbo the charge density
J(r,t) the current density
r the space variable
t the time variable
t' the delayed time t'=t-R/c
c the vacuum speed of light
R the distance between the observation point r and the point of integration r'
T T the vacuum permittivity
T T the vacuum permeability
with : TTT T $\varepsilon_0\mu_0$

For perfect conducting wires with a circular cross section which is small compared to the wavelength of the higher frequency of interest, the thin wire approximation can be employed.

We get therefore a set of integro-differential equations which relates the vector potential tangent to the wire, the scalar potential, the incident electric field tangent to the wire, the current and the linear charge density :

$$(2)\begin{cases} \dfrac{\partial A}{\partial t} + \dfrac{\partial \Phi}{\partial x} = E \\ A(x,t) = \dfrac{\mu_0}{4\pi}\displaystyle\int_\Gamma \dfrac{I(x',t')}{R(x,x')}dx' \\ \Phi(x,t) = \dfrac{1}{4\pi\varepsilon_0}\displaystyle\int_\Gamma \dfrac{q(x',t')}{R(x,x')}dx' \\ \dfrac{\partial q}{\partial t} + \dfrac{\partial I}{\partial x} = 0 \end{cases}$$

where : I(x,t) is the current
q(x,t) the linear charge density
x the curvilinear abscissa

This system is usually solved by numerical methods like M.o.M. which involves matrix inversion.

Unfortunately, the matrix size could be a limiting factor for the analysis of large thin wire structures at small wavelength.

That is the reason why we propose in this article to develop an alternative method to the M.o.M. which solves the system (2) without linear system resolution but by a fully explicit time stepping technique. Moreover, in order to solve the storage problem due to the evaluation of the delayed potentials, we proposed a management of the stored data by using a partial differential equation which, taking part from the 1/r potentials decrease, enables a very significant gain in the required storage capacity without noticeable accuracy damage.

Optimum Design of Radar Pulses for Stealth Targets

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In this paper, principles of optimum design method of radar nonsinusoidal pulses for stealth targets will be presented.

To extract the principles of the method, first we have to obtain a time-domain performance of the special absorber which is used on the target.

Using the results of this time-domain approach, we can design an optimum pulse figure to maximize the reflected wave enrgy from the surface of the stealth target.

This optimum pulse figure is not necessary unique.

In this paper we use a single layer model for absorbing material, but this method also can be generalized for multiple layer absorbing materials.

Also we suppose there is only some attenuation during pulse propagation in absorbig material (there is no dispersion). Results of the time domain analysis of such absorbing layer over metal backing plate, using the transmission line model in [2], can be found in [1]. Results of [1] can be specialized for single layer absorbing material, the main problem which is the transmission line model was exactly and completely solved in [2].

Then we show, for same absorbing material structure and same reflected energy with [3], one can use nonsinusoidal radar pulses with larger time-width (narraw-band pulses). So it is not necessary for pulses with larger time-width (narraw-band pulses). So it is not necessary for pulses time-width to be less than propagation delay time in the absorbing material (as it was qtated in [3]).

Finally some optimum nonsinusoidal radar pulses are presented for some special applications of stealth targlts.

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Session E01
Monday, July 13, PM 13:40-17:40
Room K
Neural Network Techniques in Electromagnetics

Organiser : K. S. Chen

Chairs : A.J. Chen, L.R. Cander

A Limited Survey of Neural Networks Applications for Remote Sensing Problems

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The attractive features of neural networks promises emerging applications in many areas of science and engineering. As was well known, the neural networks has been well established and successfully applied in diverse disciplines mainly due to its inherent properties and capabilities, namely, nonlinear input-output mapping, adaptability and fault tolerance and generalization, etc. Although progress has been made significantly in the past, utilization of neural networks has not yet been fully explored, at least in the remote sensing society. Remote sensing technology represents an inter-discipline applied electromagnetics. Both forward and inverse problems should be addressed.

The forward problems study is fundamental to understanding the physical insight into the remote sensing data. They are usually approached by means of theoretical modeling, numerical simulation and experimental observations. The inverse problems, on the other hand, involves the information extraction and sometimes data manipulation and handling. In the light of neural networks applications demonstrated in the past, it is reasonably projected that the use of neural networks to remote sensing, particularly for inverse problems, will be more widespread.

Because the applications spectrum is so broad and diverse, a full survey is not possible. This paper simply provides a limited review of neural networks applications in remote sensing based on the public literature.

It should be emphasized however that the survey is not necessary served as prediction of future direction of neural networks.

Neural network for the automatic detection of buried utilities and landmines

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The task of locating buried utilities and landmines using ground penetrating radar is addressed, and a novel processing technique computationally suitable for on-site imaging is proposed. The developed system comprises a neural network classifier, a synthetic aperture radar signal processing stage, and additional pre-processing, feature-extraction and image processing stages. Automatic selection of the areas of the radargram containing useful information results in a reduced data set and hence a reduction in computation time. A backpropagation neural network is employed to identify portions of the radar image corresponding to target reflections by training it to recognise the Welch power spectral density estimate of signal segments reflected from various types of utility pipes and landmines. This results in a classification of the radargram into useful and redundant sections, and further processing is performed only on the former. From the shapes of these reflected wavefronts is estimated the propagation velocity in the soil, and synthetic aperture time domain processing is then applied to this subset of the image to generate a high resolution reconstruction of the subsurface, with reduced computation time. The system was tested on data containing pipes, cables and anti-personnel landmines, and the results indicate that effective automatic detection and mapping of such structures can be achieved in near real-time.

Neural Network Approach to Low Angle Radar Tracking

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Radar tracking can be done by comparing the phase differences between the signal received at each element of an array of antennas. The indirect path reflected from the ground surface, known as the multipath effect, substantially degrades the performance of the antenna array especially at low angle. The ground clutter depends on the operating frequency and surface roughness, among others. In this study, a dynamic learning neural network is utilized to solve this problem. The dynamic learning algorithm adjusts the network weights in a linear fashion by making use of the Kalman filtering technique so as to improve the convergence rate substantially over the back propagation (BP) learning algorithm. As a demonstration, the dynamic learning neural network is applied to estimate the direction-of-arrival, including both elevation and azimuth angles, of a moving target. With the aided of an altimeter equipped on the moving target, it is possible to locate the target's position precisely. Training data are generated from a simulated model with the multipath effect taken into account. Comparisons between the performances of different arrangements, linear and planar, of the antenna array are made. Experimental results indicate that the dynamic learning neural network is capable to offer a satisfactory performance for the low angle radar tracking problem.

Neural Computation of Mutual Coupling Coefficient Between Two Rectangular Microstrip Antennas With Various Substrate Thicknesses

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In microstrip antenna array designs, it is important to determine the effect of mutual coupling between antenna elements because it can result in mismatches of the individual elements to their feeds, and the degradation of the radiating properties of each of the coupled antenna elements, such as radiation patterns, gains, polarization, and variation with scan angle. In the presence of mutual coupling the amplitude and phase of the field radiated by an array element will not be directly proportional to the amplitude and phase of the excitation on that element. But if the mutual coupling between array elements can be calculated, the feed excitations can be adjusted to compensate for this effect. From the articles in the literature it is seen that the certain way of calculating the mutual coupling coefficients involves the complicated methods. These methods involve extensive numerical procedures, resulting in round-off errors, and may also need final experimental adjustments to the theoretical results. They are also time consuming and not easily included in a computer-aided design (CAD) system.

In this work, a new simple method based on artificial neural networks for calculating the mutual coupling coefficients between two probe-fed rectangular microstrip antenna elements in E- and H-plane coupling configurations has been developed. The back-propagation algorithm is used to train the networks. Ability and adaptability to learn, generalizability, smaller information requirement, fast real-time operation, and ease of implementation features have made artificial neural networks popular in the last few years. Because of these fascinating features, artificial neural network has been used in this work to calculate the mutual coupling coefficient. The neural model used in this work takes also into account the surface wave effect. The mutual coupling coefficient results obtained by using the neural model are in very good agreement with the theoretical and experimental results reported elsewhere. This very good agreement supports the validity of the neural model.

Because the neural model presented in this work has high accuracy and requires no complicated mathematical functions, it can be very useful for the development of fast CAD algorithms. This CAD model, capable of accurately predicting the mutual coupling coefficients of rectangular microstrip antenna arrays, is also very useful to antenna engineers. Using this model, one can calculate accurately, by a personal computer, the mutual coupling coefficients of rectangular microstrip antenna arrays, without any background knowledge of microstrip antennas. It takes only a few microseconds to produce the mutual coupling coefficients on a PC Pentium/133-MHz computer. Even if the training time takes less than 10 minutes, after training, the calculation time is less than 100 μs in real-time calculation. Thus, the neural model is very fast after training.

Results calculated by the neural model agree well with the measured results.

Neural Network Applications in Ionospheric Studies

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The ionosphere of Earth exhibits considerable spatial changes and has large temporal variability of various time scales related to the mechanisms of creation, decay and transport of ionospheric plasma. A number of recent papers deal with the efforts to improve existing physical, empirical and semi-empirical ionospheric models beyond their climatological level. They have mostly been concerned with worldwide or regional aspects of this complex phenomenon using a detailed time-dependent description of energy, ionization and momentum sources for the coupled magnetosphere-ionosphere-thermosphere system. However, some of the inputs to those models are poorly represented thus limiting their ability to predict the relevant events. Another way to address this problem is by applying artificial intelligence methodologies and neural network computation techniques to current solar-terrestrial and ionospheric data. It appears that modern development of numerical models for ionospheric monthly long-term prediction and hourly short-term forecasting may proceed successfully applying neural network as in essence, a non-linear prediction filter. The performance of this technique is illustrated with a neural network developed to model the temporal variations of ionospheric critical frequency foF2 that corresponds to the peak electron density in the F region. The hybrid time-delay Multi-Layer Percepton predicts foF2 from past values, the appropriate daily solar and planetary magnetic indexes. It has a prediction horizon of few hours. Architecture of this neural network is designed to provide high-accuracy forecasting of foF2 on the time scale of an hour or two and reasonably accurate day-ahead foF2 forecasts.

Comparisons between results obtained by the proposed approach and measured foF2 values provide prospects for future applications of neural networks in ionospheric studies.

Automatic Scaling of Ionospheric Parameters Using Fuzzy Classification Techniques

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Synoptic ionospheric measurements in the form of ionograms have provided valuable information both for the HF communications as well as for studies related to the physics of the ionosphere. In this report, a method for the automatic identification and scaling of ionogram traces using fuzzy classification techniques has been developed for digital modern ionosondes of the digisonde and the NOAA HF radar class. The primary input for fuzzy processing is a two-dimensional (frequency-virtual range) image with amplitude and polarization information. In the autoscaling algorithm described here, a measure of the continuity or discontinuity between ionospherically reflected echoes can be obtained using a fuzzy relation that describes a set of rules for echo connectedness. Based on such measures, segmentation processing of ionograms can be defined and their properties obtained. Segments representing the ordinary and extraordinary reflections from the E- and F-layers can easily be differentiated from multiple hop echoes. By choice, the major segment to be derived is usually the F-layer trace, although the daytime E-layer trace can also be obtained. These echo traces can be provided to scaling process or inversion procedures, which can derive either the set of ionospheric parameters (foE, h'E, foF1, foF2, h'F2, etc.) or the electron density distribution in the overhead ionospheric plasma.

A Neural Network Approach to Passive Microwave Remote Sensing of the Soil Moisture

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Passive microwave remote sensing can be used to estimate geophysical parameters through a dependence of microwave brightnesses on the parameters of interest. The dependence is often highly nonlinear so that one has to use a retrieval scheme with the capability of resolving non-linearity. Artificial neural networks are well-known for its capability in managing nonlinear mapping relations. The use of a neural network requires that enough training data be available to be representative, while this might become impractical in the field of remote sensing because a great amount of ''ground truth'' can not be easily obtained.

In this paper, we will combine a Dynamic Learning Neural Network(DLNN) and a Land Surface Process/Radiobrightness (LSP/R) model to study the retrieval of soil moisture over grassland. The LSP/R model is a physically-based model including two modules, an LSP module and an R module. The LSP module simulates land-air interactions of coupled heat and moisture transfer, and estimates the temperature and moisture profiles of the soil and canopy. The R module predicts radiobrightness using a refractive mixing model for the canopy. The DLNN is a multilayer perceptron network based on a polynomial basis function expansion. Its output layer is in a linearized form while the hidden layers remain nonlinear. This allows us to adopt a dynamic Kalman filtering algorithm for the purpose of adjusting the network weights with a recursive minimum least square error sceheme. As a result, the DLNN has the features of fast learning and built-in optimization of a weighting function at a little expanse of the computer storage.

We will present results from a case study to evaluate the approach of retrieving soil moisture using the DLNN trained with the LSP/R model. The study is based on results from a 60-day dry-down simulation of the LSP/R model for a prairie grassland in summer. We utilize 10% of the model predictions to train the DLNN and the rest of the predictions are used to evaluate the DLNN retrievals. The training data include horizontally- and vertically-polarized brightnesses at 1.4, 19, and 37 GHz for an angle of 53 degrees, and the corresponding temperatures and moisture contents of the soil and canopy. To realize the study, we intentionally introduce different levels of noise to the input nodes of the DLNN, i.e., radiobrightnesses, so that the performance of the retrieval approach can be better justified.

Application of Supervised and Unsupervised Neural Networks to remote Sensing Image Classification

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Image classification from remote sensing data has been used for various applications. Conventionally, the development of classification methods has based on the statistics of the data, and these methods are often applied to the images obtained by optical sensors. Recently, the use of neural networks for image classification have received a great deal of interests. Although it is shown that the classification accuracy of neural network models is comparable with, or slightly better than, conventional statistical methods, again the results are applied to optical images. This study demonstrates the application of neural network techniques to SPOT and polarimetric SAR images classification, which denotes the classification for both optical and microwave images.

Two neutral networks are adopted in this study: supervised dynamic learning model and unsupervised adaptive resonance theory 2 (ART2). The dynamic learning neural network is a supervised approach which consists of modified multi-layer percepton in which power series was used to represent the activation function of the hidden layers. It employs the Kalman filter technique as its learning rule.

The unsupervised ART2 possesses a number of distinguishing features. First of all, it performs model-based learning that precludes unrelated prototypes from learning, so as to preserve the previously learned knowledge. Secondly, ART2 can self-adapt, in real time, its configuration for retaining category codes in response to input patterns presented in any order. Thirdly, ART2 is able to use the pre-defined parameters to proceed the model without going through trial and error process. Both supervised and unsupervised neural networks are tested by SPOT and SPOT and polarimetric SAR images. The classification results indicates that both supervised and unsupervised neural networks can reach a fairly high accuracy compared with the ground investigation.

A Neural Network Based Linear Antenna Array Processing for Highly Reduced Side-Lobes

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In adaptive antenna arrays (AAA), shaping the array factor is a challenging task where different sophisticated adaptation algorithms might be utilised. Applying these algorithms to AAA results in limited performance, due to slow convergence rates and increased computational complexity. The high cost required is another factor that should be taken into consideration. From another point of view, the synthesis of linear arrays to produce highly reduced side-lobes is a problem of similar complexity and limitations. This paper suggests a new synthesis technique for antenna array system based on a trained Neural Network (NN). In particular, the in-phase and quadrature-phase components of the output of a linear array are processed by two NN's. The simulation results show that the NN when trained to minimise the side-lobes levels of the array result in highly improved patterns with very deep side-lobes. This method substitutes other tedious conventional algorithms that are usually used in adaptive antenna arrays and array synthesis. The training of the NN's is based upon the backpropagation technique. Two types of patterns are investigated. The first one is a sidelobe free array with desired main-lobe characteristics. The second one is a pattern with deep nulls at a number of specified directions (estimated interference directions).

Acquired Data Application on an Image Data Compression Technique

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SUMMARY :

A split neural network system, for image compression, with a single hidden layer pattern transmission or data storing of the hidden vector, is proposed in this paper. It depends mainly on the splitting of the neural network, the input and hidden layer in the transmission side and the output layer in the reception side.

The output of the hidden layer which is the compressed form is the data transmitted on the channel.

Better reconstructed images can be obtained if a variety of different activity images are used in the design phase of the proposed neural system.

A back propagation training algorithm is used to learn a single layer neural network of 16 input nodes and 16 output neurons assuming an ideal transmission of the hidden vector.

The image data acquisition technique is proposed. The used digital camera is produced by Casio and called QV - 10 . Using such a camera, it becomes easy to reduce images with resolution 320 x 240 pixels.

Although the used camera QV - 10 produces the worst images comparing with other digital cameras due to the low resolution, these images can be modified by converting them to other better format. The digital camera is successfully produced digital data applicable for the image compression techniques.

For subjective evaluation purposes, the reconstructed images for the 4 hidden neurons and vector quantizer of 256X4 codebook size case are chosen to be painted and compared with the original images. An excellent package for displaying images called Paint Shop Pro has been used. The resultant PSNR is high comparing with the standard images used like Lena. The results of analyzing these images and the resultant PSNR which defined as :

$$PSNR = 20 * \log 10 (255 / RMSE)$$

where RMSE is the root mean square error i. e. RMSE = (sum (Xi - Xo) 2 / total No. of pixels) ½, where Xi is the input pixel value & Xo is the output reconstructed pixel value.

Bit rate bpp	PSNRdB	SNRdB	Image
0.5	28.46	13.87	Mubarak
0.5	30.62	15.12	Nilesat
0.5	28.14	13.78	Peace

Resultant PSNR for Acquired image data

Numerical Modeling of Interaction Electromagnetic Signals with Oscillator Neural Networks

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1. Introduction

The purpose of this work is development of a numerical model of interaction of electromagnetic signals with oscillator neural networks and investigation of the mechanisms this interaction.

2. Method of calculation

The signal falling on the random active media models synchronouse phase coherent rayes, which are distributed uniform in plane wave front and are orientated along direction in propagation wave. The direction propagation of ray and the length of free propagation of ray in random active media is determined by stochastic manner in according to indicatrix of over-radiation of oscillator (V.G. Spitsyn, Electromagnetic Waves and Electronic Systems, 2, 45-49, 1997). Every act interaction of signal with oscillator is accompanied by displacement the frequency of signal and of oscillators vibrations.

The model is suggested, which describe transfer of signals in three dimensional oscillator neural network with stochastic connections. Every oscillator has possibility connection with all another oscillators. It agrees with Brindly's and Marr's idea (D. Marr, Proc. Roy. Soc. Lond., B176, 161-234, 1970) about chance disposition inter - neural networks. The process of interaction of signals with oscillators, disposed in spherical region is investigated.

3. The results of calculation interaction electromagnetic signals with oscillator neural network

The results of calculaton demonstrate, that after interaction of harmonic signal with oscillators, having monochromatic spectrum of vibrations, additional harmonics appear in spectrum of oscillators vibrations. The amplitude of this harmonics is decreased with growth number of acts interaction.

Influence of harmonic signal on the oscillator neural network with disperse of frequency oscillators' vibrations leads to decreasing of width of frequency spectrum of oscillators' vibrations and in the limit to monochromatization its form. Therefore we may do the conclusion about then that in process of function oscillator neural network with external electromagnetic influence the synchronization of oscillators, taking part in process stochastic transfer of signals, takes place.

4.Conclusion

In this work a model interaction of electromagnetic signals with oscillator neural network is offered. The results of modeling influence of harmonic signal on the oscillator neural network show that decreasing of width of frequency spectrum of oscillators' vibrations and monochromatization its form takes place.

Session F01
Monday, July 13, PM 13:40-17:20
Room B/C
Microstrip and Resonator Antennas

Organiser : L Shafai

Chairs : L Shafai, Y. Antar

Investigation of Mutual Coupling between Multi-Segment Dielectric Resonator Antennas

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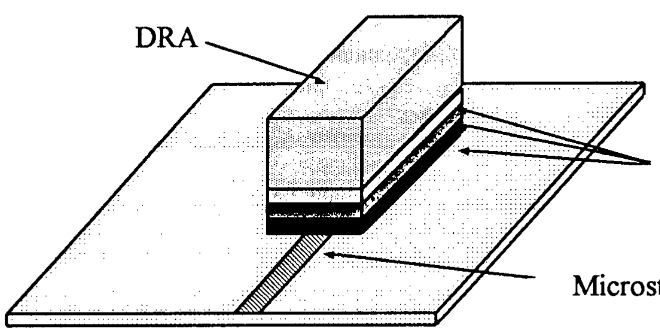
Dielectric resonator antennas (DRAs) are resonant antenna structures typically fabricated from low-loss microwave ceramics whose resonant frequency is predominantly a function of the size, shape and material permittivity. Research over the last few years has demonstrated that DRAs offer several attractive features including: high radiation efficiency (>95%) due to the absence of conductor or surface wave losses; flexibility of shape (rectangular, cylindrical, hemispherical, etc.); excitation by a variety of feeding mechanisms (probes, slots, microstrip lines, dielectric image guides, etc.) making DRAs amenable to integration with various existing technologies; a wide range of permittivity values (from about 6 to 100) allowing the designer to have control over size and bandwidth (i.e. wide bandwidth is achievable using low permittivity and compact size is achievable with high permittivity). These features make DRAs very versatile elements, which can be adapted to numerous applications by appropriate choice of the design parameters.

The multi-segment dielectric resonator antenna (MSDRA) consists of a low permittivity DRA under which one or more thin segments of higher permittivity material are placed, as shown below. The MSDRA was developed to significantly enhance the coupling from the DRA to the microstrip feed line, while still maintaining a wide impedance bandwidth [1]. MSDRAs have been used in various linear and planar arrays operating at frequencies ranging from C- to Ku-Band [2,3]. In the array environment, mutual coupling between elements can play a significant role in the array performance, especially for electronically scanned arrays. This paper will report on an investigation of the mutual coupling between MSDRA elements. Experimental data on E-plane and H-plane coupling between MSDRAs, as a function of element spacing, will be presented. This data can then be used in array designs to control the effects of mutual coupling.



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Effect of Finite Ground Plane on the Directivity of the Microstrip Square Ring Antennas

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Microstrip antennas being, low profile and light weight are being popular for various applications. method for miniaturization of the microstrip patch antenna without degrading its radiation characteristics is investigated. It involves perforating the patch to form a microstrip square ring antenna, which is investigated numerically and experimentally. The ring geometry introduces additional parameters to the antenna that can be used to control its impedance, resonance frequency, and bandwidth. For a single square ring increasing the size of perforation increases its input impedance, but decreases its resonance frequency and bandwidth. To match the antenna to a transmission line and also enhance its bandwidth, the ring is stacked by a square patch or another square ring. The computed results are compared with experimental data and again good agreement is obtained.

The perforation size, has a negligible effect on the directivity. This is surprising result, since by increasing the perforation size the antenna physical size decreases, and it is expected that its effective aperture, A_{em}, also to reduce, reducing the directivity according to $D_o=4\pi A_{em}/\lambda^2$. However simulation and experimental results show that the antenna directivity and, consequently, its effective aperture are independent of the ring size, and may even increase with increasing its perforation.

To verify the effect of ground plane size, extensive simulation and experiment were carried out. Two cases of single layer and one cases of double layer were considered. It was found that, the ground plane size effects the resonance frequency, input impedance, and radiation pattern. However the main effect is on the directivity of the antenna which can be controlled by choosing the size of the ground plane. It maximizes when the ground plane is $1.1\lambda_o$ (λ_o is the free space wave-length). The efficiency of the two layer microstrip ring-ring antenna at this size is better than 95%. These results will be provided during the presentation.

Modified Waveguide Model for the Rectangular Dielectric Resonator Antenna

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Recently, much effort has been devoted to the dielectric resonator antenna (DRA) with aperture-coupling mechanism, due to its flexibility in the design of feedline and DRA separately. In predicting the operating frequency of DRA, the closed cavity model with perfect magnetic conductor (PMC) walls, waveguide model method, and numerical methods (e.g., surface integral equation incorporated with the moment method, boundary element method, null-field method, eigenfunction expansion method where the boundary condition is treated in the lease-squares sense, and finite-difference time domain method) have been applied. Although the versatile numerical methods can generate accurate results, they may be inflexible for the design of DRA due to their time-consuming computation. The closed cavity model with PMC walls, due to its lack of accuracy, has not been applied since 1970s. The waveguide model method, which yields resonant frequencies within 1% with respect to the experimental results for the circular DRA, would give rise to somewhat bigger error as applied to the rectangular DRA, although it can sometimes be useful in developing impedance modes (e.g., Y. M. M. Antar and Z. Fan, IEE Proc.-H 143, 113 (1996)).

On the other hand, since the operating bandwidth of a DRA is dominated by its aspect ratio, the two aspect ratios of rectangular DRA would provide more flexibility in the bandwidth control than the circular DRA. Therefore, a modified waveguide model would be useful which is fast and can generate precise prediction of resonant frequency for rectangular DRA.

According to the argument of Van Bladel (J. Van Bladel, IEEE Trans. MTT-23, 199 (1975)), even the DRA with very high permittivity can not be rigorously treated with the PMC model. However, we note the portion of the electromagnetic energy confined within the DRA is closely related to the value of the permittivity. Noticing this phenomenon and reasonably assuming the portion of the electromagnetic energy confined within the DRA is closely connected with the resonant frequency, a concept of effective dimensions is proposed to modify the conventional waveguide model so as to more accurately predict the resonant frequency of the ground rectangular DRA with aperture-coupling.

To examine the accuracy of this new modified waveguide model in predicting the resonant frequency of rectangular DRA, computed results from the present model are compared with the experimental results as well as the results computed from the commercial software Micro-Stripes, and with those calculated by the conventional waveguide model. The comparison reveals that the present model is generally more accurate than the conventional one, and could generate comparable results to the numerical simulations with much less computation time. The accuracy and fast features of the present modified waveguide model establish its usefulness in predicting the operating frequency of the ground rectangular DRA with aperture-coupling. Use of the present model in the design of rectangular DRA and its associated applications are presented.

Gain Improvement for Annular Slot Array Antenna

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Annular slot array antennas have many attractive features like high gain and simple structure which make them suitable for applications such as satellite and mobile communications. The basic element of these antennas is a slotted radial waveguide. Slots are co-centred and continuous. By proper excitation this antenna is capable of radiating in broadside. The radial waveguide can be filled by a dielectric, however in current study the medium is air. Simulations have been done by the "Multi-Body Electromagnetic Scattering" (MBES) package, developed by the University of Manitoba. This software uses the method of moment for bodies of revolution. Because the structure of radial waveguide antenna is rotationally symmetric the method of bodies of revolution is applicable.

The antennas with two and three annular slots excited in TM11 mode are studied. Two methods of gain improvement are suggested, first by adding a radome made of dielectric material with relative dielectric constant (epsilon-sub-r), second by adding conducting strips on the top of each slot. Fig 1 shows the results of adding a radome of thickness t and relative dielectric constant 2.5, 4 and 6, for antennas with two and three radiating slots. By adding this radome, the gain can improve up to 2dB for two-slot antenna and 5dB for three-slot antenna. Although adding radome gives good gain improvement, it is expensive and makes the antenna bulky and heavy. A low cost alternative method is adding conducting strips of width w and thickness t on top of each slot a t a distance of quarter free-space wavelength. Table 1 shows the gain for two- and three-slot antennas for different w and t combinations. It is interesting to note that for t about 0.2 wavelength gain is maximum, independently of the strip width. Also for w=0.4*wavelength the gain is maximum for both antenna types.

Table 1 : Gain(dBi) for different combinations of strip sizes

w/wave-length	t/wave-length	2slots Gain(dBi)	3slots Gain(dBi)
without strips		15.971	17.837
	0.1	16.693	19.255
0.3	0.2	17.550	20.160
	0.3	17.162	19.044
	0.1	17.122	20.508
0.4	0.2	18.367	21.111
	0.3	17.126	18.592
	0.1	16.961	20.952
0.5	0.2	17.719	20.982
	0.3	16.276	18.503

Wide Band Antenna Suitable for MMIC Applications

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Emerging new communication systems have increased the demand for dual band antennas that are small in size, low in cost and weight, and which are easy to design and fabricate. Furthermore, these new antennas need to be easily integrated with passive and active devices for both MIC and MMIC technologies.

In this paper we present results on a new type of antennas that incorporate a spur-line filter with the radiating element to achieve dual or wide band operation. Integrating the filter with the antenna offers several advantages, while maintaining the antenna size and the flexibility to choose a large design frequencies spread. Several designs were simulated and implemented using coplanar wave-guide configurations, which are more suitable for MMIC applications. A number of antennas were fabricated to operate at X-band (10 GHz) and Ka-band (34 GHz). The first was built on RT/Duroid 6010 ($\epsilon_r = 10.2$) and the second was built on a GaAs substrate ($\epsilon_r = 12.9$, thickness 625 u m). Close agreement between the measurement and simulation results was obtained.

An Electromagnetically Coupled Microstrip Array with Taylor Distribution

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The electromagnically coupled array consists of microstrip patches placed in proximity of a feedline on the same plane of a single layer substrate. The coupling takes place through a narrow gap between the patch and the fedline. Two excitation methods namely standing-wave or travellin-wave can be utilized in this configuration. The gap size can be adjusted to control the coupling to the patch. A single patch configuration can be used to determine the relation between the gap size and the power coupled to the patch.

Two types of polarization with respect to feedline current can be obtained. The vertical polarization is when the patch resonant length is normal to the feedline, where as in horizontal polarization the resonant length is parallel to the feedline. In standing-wave excitation, the vertical polarization is best achieved when the patch is positioned at the voltage standing-wave maxima. The current standing-wave maxima are the source of magnetic coupling and useful for horizontally polarized resonators. The traveling-wave excitation can easily be obtained by simply match terminating the feedline open end. While the patch position constraint in standing-wave case no longer exists in the traveling-wave excitation method, the antenna efficiency is reduced due to undesired cross-polar radiation and energy transfer to the load.

Astanding-wave array with 10 elements (shown in Figure1) is simulated at 12 GHz for WHICH THE Taylor distribution with -20dB SLL and 3 equi-level side lobes is configured. The design curve obtained for a single patch structure is used to determine the gap distribution across the array. The simulated radiation pattern (Figure 2) of the array indicates the correct approach in design. The minimum feasible gap size (in this instance is chosen to be 0.1 mm) determines the maximum obtainable coupling. The experimental results will be obtained in the near future.

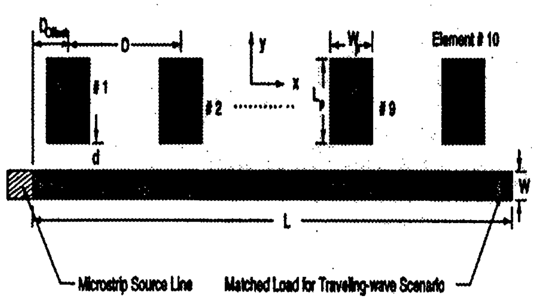
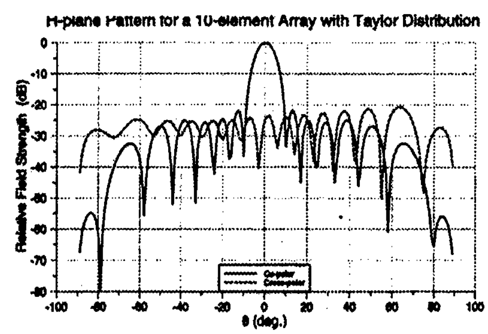


Figure 1: Geometry of Electromagnetically Coupled Microstrip Array



All dimensions in mm

Gap distribution: $d_{1,10} = 0.4375$; $d_{2,9} = 0.375$, $d_{3,8} = 0.25$, $d_{4,7} = 0.1625$, $d_{5,6} = 0.1$

$L_p = 8.2$, $D = 18.2 \approx \lambda g/2$

$\varepsilon_r = 2.55$; $h = 0.79$, $L = 176.462$, $W = 0.61$, $W_p = 4.45$

Figure 2: H-plane Radiation Pattern of an 10-element Array with Taylor Distribution at 11.8 GHz.

Improvement of Conical Horn Performance using Metallic Discs

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Horn antennas, pyramidal and conical, are among the simplest and widely used antennas at microwave and millimeterwave frequencies. Their widespread application stems from the simplicity of their construction, ease of excitation and large gain. However, they suffer from a number of deficiencies due to phenomena like spillover, phase error in the aperture field distribution or cross-polarization, resulting in reduced aperture efficiency of about 50% to 60% for optimum gain horn.

Improvements of the horn performance have been achieved by design modifications such as corrugated horn, dielectric loaded horn and lens-corrected horn [1], each of which offers specific horn parameter improvement. The latter case, i.e. the lens-corrected horn, is the special case that improves the horn aperture phase distribution and consequently, enhances its gain. However, for large flare angle the lens becomes bulky and requires high dielectric permittivities with increased cost and difficulties in impedance matching.

A simple method, introduced by Koerner and Rogers [2] for pyramidal horns, is investigated in this paper for conical horns. It consists of introducing a metallic disc inside the horn, at an appropriate distance from its aperture. The initial investigations are carried out by simulations, using a numerical code based on the method of moments for bodies of revolution [3]. Different horn flare angles are considered, and the initial results show directivity improvements comparable to lens-corrected horn. As an example, for a 30° flare angle horn the aperture efficiency was increased from 61% to 85%. These results will be confirmed by measurement and provided during the presentation.

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Analysis of Effects of Microstrip Stub on Operating Frequencies of Microstrip-Fed Slot Antennas

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Recently much attention has been focused on the performance of various types of slot antennas fed by the microstrip line. This is mainly due to some of the interesting properties of these antennas, including the relatively large bandwidth, efficient radiation when fabricated on high dielectric constant substrate and easy interface with microstrip circuits.

Usually the slot antenna fabricated on a dielectric substrate is fed from the back-side using a microstrip line extended a quarter-wavelength beyond the slot position. Since the input impedance seen at the middle of the slot is very high at the fundamental mode of the slot antenna, the use of a quarter-wavelength stub results in a high reflection if a 50 ohm microstrip line is employed for feeding the antenna. In such cases, the stub length is chosen to be different from a quarter-wavelength in order to achieve a reasonable match to the feed line. The change of the stub length from the quarter-wavelength shifts the operating frequency from the natural frequencies of the slot antenna.

This paper is concerned with the investigation of the effects of the stub length on the operating frequencies of the slot antenna using the full-wave spectral domain technique. In the analysis, the microstrip line is assumed along the x-direction with the electric current distribution $J_x = J_x^{inc}(x) + J_x^{ref}(x) + \sum_n I_n f_n(x)$ and the slot is assumed along the y direction with the magnetic current distribution $M_y = \sum_m E_m s_m(y)$. In the above equations $f_n(x)$ and $s_m(y)$ are piece-wise sinusoidal basis functions, $J_x^{inc}(x)$ and $J_x^{ref}(x)$ are the incident and reflection travelling-wave basis functions and I_n and E_m are the weights determined after solving the final matrix equations.

At various resonances (operating frequencies), the magnitudes and phases of the slot field are presented and the resulting radiation patterns are shown. Using the theoretical results, it is also shown that due to the presence of the microstrip line, the slot antenna can support modes with a pseudo-electric wall symmetry. These modes have low impedance. It was found that when the operating frequency of a slot antenna is around these modes, the antenna can be satisfactorily matched to a 50 ohm microstrip line. Example results are shown in Fig.1.

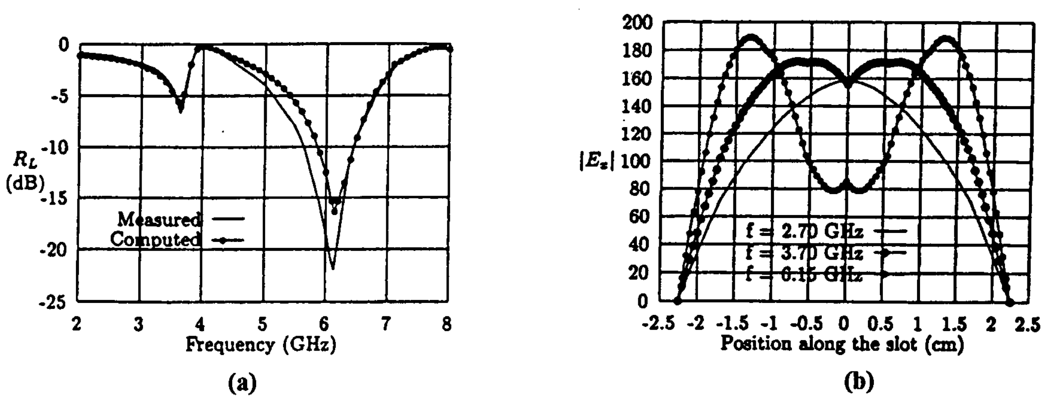

Fig.1 (a) Computed and measured return-losses of a slot antenna. (b) Computed slot fields at the two frequencies shown in (a) and at the first natural frequency of the slot antenna.

Stacked C-Patch Antenna Partially Short–Circuited

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This paper describes a small coaxial fed probe antenna with two stacked C-patch elements partially short-circuited. The antenna (fig. 1) is obtained from a dipole (fig. 2) designed with two C-patch elements connected together in the opposite direction using a partial short-circuit plane and folding along the axis of symmetry. Unfortunately, this dipole gives a first resonant mode which does not significantly radiate. This effect is due to a phase opposition of the electrical current densities on the surface of each element. This C-antenna is realized using two stacked C-patch in order to obtain a radiating structure with a half dimension side compared to the unfolded configuration (fig. 2) at the same frequency. The size length of the radiating element is about $\lambda/12$ in comparison with conventional half or quarter wavelength microstrip antennas or other short-circuited configurations. The antenna is made on air substrate and present a resonant frequency centered at 2 GHz with a bandwidth of 3 percent. The structure is placed on a square ground plane with slightly larger dimension compared to the radiating element and can be easily matched by adjusting the position of the feed point. Isotropic characteristics of the radiation patterns are also obtained with a weak purity of polarization which results from the small size and the relative complexity of the geometry. Thus, this compact and low cost antenna can find use in mobile communication systems. The effect of the ground plane size on input impedance, radiation patterns with a parametrical study have been analyzed and discussed.

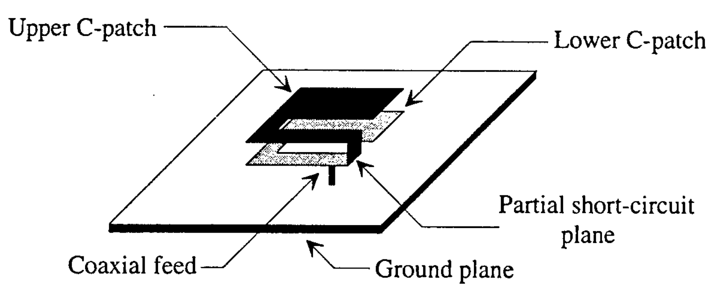

Fig. 1 Geometry of the C-patch antenna

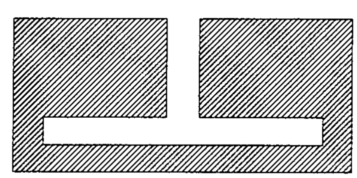

Fig. 2 Folded dipole

Reference
G. KOSSIAVAS, A. PAPIERNIK, P. BRACHAT, J. CAZAJOUS, P. RATAJCZAK : "Antenne imprimée plane à éléments superposés court-circuités", Patent No 97 460030.6-2206.

Stratified Surface Finite Element Method for Arbitrary Multilayered-Multielement Printed Antennas

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Asurface finite element method based on stratified Green's functions in multilayered printed antennas is presented. Explicit as well as implicit general expressions of the stratified Green's functions are not obvious and become very complex as the arbitrary numbers of dielectric layers and metallic elements increase.

External boundary conditions on the two opposite sides of the structure (free-space boundary and on the metallic ground plane) and internal boundary conditions on different layer interfaces yield a linear system, for which we propose an original iterative solution method. Insted of calculating all the expressions for the Green's functions in each medium directly (i.e. searching for the solution of the global linear system) as it is done in most of classical methods, the idea is to transfer the two external boundary conditions in the same layer. This transfer is carried out by using linear boundary conditions between internal layers.

This method deals with an arbitrary number of different dielectric layers and the presence of metallic elements on the interfaces can be taken into account. This efficient solution procedure, coupled with a finite element formulation on understructured triangular discretizations yields a very eficient tool for the numerical simulation of arbitrary multilayered-multielement printed antennas with complex geometries.

Different comparisons with other numerical methods have been made. Other numerical methods include a surface finite element method with free-space Green's function [1] and a moment method based on a mixed potential integral equation with rectangular cells ond roof top shaped basis functions [2].

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Session G01
Monday, July 13, PM 13:40-15:20
Room M
Microwave Phase Shifters, Circulators and Attenuators

Chair : A. Priou

Microwave phase shifters based on ferroelectric films.

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The phase shifters are the main elements to create transmitter-receiver systems with phased array antennas. Early studies of nonlinear dielectric behavior and microwave losses of ferroelectric $SrTiO_3$ (STO) and $(Br,Sr)TiO_3$ (BSTO) films have demonstrated the potential of these materials for microwave applications [1, 2]. The devices employing ferroelectric films are distinguished by their great speed of tuning, sufficiently low microwave losses, low drive power, high radiation resistance and low cost. Besides the advantages mentioned above these phase shifters enable to operate in analog regime (continuos variation of phase shift) that make it possible to use the single ferroelectric phase shifter instead of multi-bit digital semiconductor phase shifters. The present paper is devoted to design and experimental testing of analog phase shifters based on $(Ba,Sr)TiO_3$ and $SrTiO_3$ ferroelectric films.

A construction of phase shifter contains rat-race hybrid coupler, two reflective terminations and bias circuit. The reflective terminations consist of series combination of ferroelectric (FE) capacitor and inductor. STO and BSTO film capacitors were manufactured by planar technology. Operation temperatures of the device were 77K and 300K for STO and BSTO films respectively. The following experimental results was achieved: continuos phase shift is 0÷110° in 0÷400V controlling voltage range, the figure of merit is 100°/dB, relative phase shift error less than 3% in operation frequency range 1.7÷2.0GHz and insertion losses are 1.0±0.4dB.

One of the main advantages of the phase shifter presented is the high power handling capability. Calculations performed on the base of intermodulation distortion measurements [3] shows that summed harmonic level is less than 30dB in comparison with level of fundamental signal under input microwave power 10Watt (1.9GHz).

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Field Theory Analysis of Microscrip Circular Using Contour Integral Method

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In this paper an exact field theory treatment for the microstrip junction circulator problem is presented. The contour-integral method is used as a numerical technique to solve this type of problems. In this technique the problem is formulated as an integral equation over the physical boundaries by using the free space Green's unction. The integral equation is then solved numerically at the periphery of the circuit by discretizing the periphery into a number of sections and consequantly, the solution results in a system of linear equations which can be arranged in a matrix form. Following this, the electric and magnetic boundary conditions are applied, respectively, to the system of equations and the circulator characteristics namely, reflection coefficient, insertion loss and isolation are obtained in terms of the electric and magnetic field components along the periphery in both constant electric and constant magneticfields. The impedance matrix parameters are obtained from the scattering to impedance matrix transformation, then the input impedance of the microscrip circulator is obtained.

Two main advantages arise in dealing with the contour-integral technique over the other numerical methods. The first, the computation time doesn't exceed than few seconds in execution of the whole program including several mathematical statements with large size matrices using personal computer. The second, it can analyse any arbitrary shape of microstrip circuit periphery by discretizing its contour to N equal sections, then dealing with the contour-integral equation in the numerical form becomes very simple. On the other hand, it gives an approwimate solution as in the other numerical methods.

In order to check the validity of the theoretical analysis, correctness of the program and the accuracy of the method, the cases of single-port junction and two-port junction were studied and the computed results were compared with the available published date. Good agreement was found. The design curves for the case of disk and clover leaf circulators were computed fro different geometric dimensions and physical parameters.

A three-port microstrip ferrite circulator was fabricated using thin film technique and photolithography. Measurements were caried out and good agreement was found between calculated and measured performance characteristics.

Detailed Matching Characteristics of a Punched Ferrite EM Absorber

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Asimple method has been proposed to change the matching frequency characteristic and improve the matching characteristic of a ferrite EM absorber by introducting the idea of making small holes in the rubber ferrite material [1] [2]. Simply by making small holes in the ferrite the matching frequency can be easily changed in the microwave frequency. It is also possible to reduce the matching thickness.

In this paper, these matching characteristics are investigated in more detail both theoretically and empirically. On the basis of the Spatial Network Method (SNM), the changeable matching frequency characteristic and the present matching characteristic related to permeability are analyzed. In this analysis, the frequency dispersion equation of permeability is taken as a parameter. To summarize the matching characteristics obtained in previous papers for the changeable matching frequency, it has ben clarified that matching characteristics are shifted toward a higher frequency region as th diameters of holes increase or the space between adjacent holes is reduced.

The matching characteristic can be improved and the matching thickness reduced by making small holes in the ferrite.

According to a detailed analysis by SNM, it is clear that there are optimum conditions fro obtaining a good matching characteristic and a broad matching frequency characteristic. When the spaces between adjacent holes are 3 mm and the diameter of a small hole is 4 mm with a ferrite thicknes of 5mm, a good matching characteristic of -50dB in the reflection coefficient is obtained at around 4GHz, for example. Broad band matching characteristics from 2 to 5.5GHz are achieved when the diameter of a small hole is 9 mm with a 5mm space between adjacent holes and a 7mm ferrite thickness. In addition, it is suggested that there is a possibility of reducting the ferrite thickness to less than 1mm through a detailed analysis of SNM. In all of these analyses, the frequency dispersion equation of permeability has been used as the value of permeability. Taking the parameter of Kf_1 ($\leq$ 10GHz) and K in this equation, the matching characteristics of punched ferrite absorber are also examined. From this analysis, it is clarified that a large value of Kf_1 is not sutable for the present punched ferrite absorber. The value 6GHz or so should be taken for Kf_1 to obtain good matching characteristics when the value of Kis greater than 100.

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Regulation of Attenuation with Minimum Phase Shift

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Steadily controlled system can be in the balance condition, or in the modes of change condition. One of the important requirements for these modes is invariable of the phase shift at regulation of the transfer factor. Else, transfer of system from one balance condition to other should be executed with the least phase error in the transfer factors range and the working frequency band.

Decision of the given problem is especially urgently at designing of the signal amplitude control systems and devices, such as controllable attenuators and adjustable amplifiers, as well as a systems of the signal automatic phasing. As a rule, for reception of the phase stability the phase discriminators, forming signals of the phase difference are entered in a system. After filtration this signal operates phase shifters, reducing the phase difference.

In considered multi-spanned systems the complete signal phasing is so difficultly achieved because of parasitic connections, from that the phase error reaches 10 - 20 degrees. Besides there are purely technical complexities with designing of the broadband phase shifters and discriminators. In this connection for simple systems it is possible bypass without closed regulation. Certainly, the accuracy of such systems in principle less, but for the majority of practical cases it happens reasonably.

The mathematical solution of the phasing signals problem is resulted in the report. According to this theorem the change of phase shift is minimum, if the relation of maximum of the system transitive characteristics in regulation range of a transfer factor is constant. Thus, we get rid from the regulation functional in the frequency domain. If the additional restrictions is not imposed on the system variable condition, the other parameters of the transient process can change arbitrary.

The practical examples of devices are resulted, in which a principle of optimum phase-invariance control is realized. The electrical controllable diode attenuators with small phase shift near three degrees in a frequency band from 0,1 MHz up to 1 GHz and the introduced attenuation range from 1,5 up to 20 dB are developed. The received results are closed to potential achievable.

The New Controllable Attenuators

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In the multichannel systems of power addition of the microwaves transistor amplifiers, signal auto-phasing, controlling capacity level etc. in many cases the independence of the response phase shift concerning effect at controlling of source signal amplitude is required. Else, for the most exact reproduction of the signal form at change of the transfer factor the constant of the group delay time in the transfer factors range and the working frequency band is required.

One way of decision this problem is used of the electrical controllable attenuators, adjustable amplifiers and other devices with independence a phase shift from transfer factor. The work principle of phase-invariance devices consists of the phase shift compensation in one or several additional channels of signal transfer. These additional channels are formed by adjusting circuits, included by special way in the device structure. Parameters of adjusting elements choose so that the change of phase shift at regulation was least. Choice of parameters is executed by results of the optimization problem decision. The purpose optimization function permits to reduce the phase shift in a working frequency band by change of parameters adjusting circuits and to increase a regulation range by change of control parameters at the some time. In general, the parameters of adjusting circuits are depend on control parameters. Hence, optimization of phase-invariance devices is assumed a finding not only best parameters of phase correction, but optimum operation modes also.

Examples of phase-invariance devices designing as controllable attenuators with practically independence a phase shift from attenuation factor are resulted. Attenuators has been assembled on p-i-n diodes. For compensation of the phase shift at regulation of the attenuation factor change the correction circuits with parameters, in 1,5-3 exceeding by diode parasitic parameters has been included in attenuators structure. In created devices the change of the phase shift in 4-5 times less, than in not correction in a frequency band from 1 MHz up to 2 GHz and regulation range of signal level up to 35 dB. The maximum attenuation is 40 dB. The received results are closed to potential achievable [1].

Reference

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Session G02
Monday, July 13, PM 15:40-17:40
Room M
Millimeter Wave Devices and Systems

Organiser : E. M. Biebl
Chairs : E. M. Biebl, G. E. Ponchak

New Developments in Microwave Photonics

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Microwave photonics is defined as the study of opto-electronic devices and systems capable of processing information at microwave rates and the application of opto-electronic techniques within microwave systems. The first part of the definition covers the increasingly important area of ultra-high bit rate optical transmission with 10 Gb/s systems in commercial service, 40 Gb/s systems under intensive development and much higher bit rates the subject of active research programmes [1]. The second part covers the growing interest in using optical techniques for the transmission and processing of microwave signals. Optical techniques are attractive for two main reasons. First, the high carrier frequency (~ 200THz for 1,550 nm wavelength operation) enables broadband microwave signals to be processed in a very small fractional bandwidth, minimising differential gain and dispersion problems. Second, the low loss and dispersion of single mode optical fibre transmission (~ 0.2 dB/km, < 17ps/nm×km for standard single mode fibre at 1,550 nm wavelength) is unequalled by conventional electrical media.

Proposed broadband cellular and related radio systems will require carrier frequencies in the millimetre-wave region, where propagation is strongly topography limited, resulting in the need for numerous closely spaced base stations. Size and maintainability requires the base stations to be much simpler than for conventional systems. This can be achieved by placing most of the processing at a central site and transferring the transmit and receive signals between central site and the base stations inanalogue form over fibre. The base station then only photodetects and amplifies on transmit and pre-amplifies and modulates on receive. Such systems are the subject of extensive research worldwide [2].

Microwave photonics is also finding application in beamformers for phased array antennas, where the relative freedom from dispersion in optical media allows high performance beamformers for wideband phased arrays to be realised [3].

Underlying these and other applications of microwave photonics are rapid advances in device technology and sub-system techniques which will form the major theme of this paper.

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Wideband Microwave Optic Link for Remote Sensing

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Introduction

Microwave (MW) or millimeter wave (MMW) modulated optical carriers over fiber optic links are an attractive alternative to coaxial cables for the transmission, the distribution and the reception of analogue signals. Consequently, they are increasingly implemented in cellular personal communication systems (PCS), in cable television (CATV) distribution networks as well as in remote antenna and sensor systems. In this paper we will address the key components for building such wideband MW or MMW fiber optic links and we will present experimental results on an IMDD MW fiber optic link for remote electromagnetic field sensing.

Wideband IMDD MW optical link for remote sensing

In optical links based on the intensity modulation direct detection (IMDD) [1] scheme the MW/MMW electrical signal is transferred into the optical domain either by a direct modulated laser diode or by using an external modulator. The MW/MMW modulated optical signal is then transmitted to a remote read out unit via an optical fiber where it is directly detected using a wideband photodiode. For wideband MW/MMW operation over long distance external modulation is often preferred [2] to direct laser modulation because of fiber dispersion. Even for low frequencies it has been shown that the link gain of external IMDD optical links is larger in comparison to direct IMDD optical links [1]. In this paper we will concentrate on wideband modulators and photodetectors which are key components for such an external IMDD optical link. In detail we will present experimental results on 70GHz wideband electroabsorption (EA) waveguide modulators [3] and on 60GHz traveling-wave photodetectors [4], which have been fabricated for such links. Furthermore, we will present the concept and results of an optical link for remote electromagnetic fields sensing (cf. figure 1). Within this fiber optic link the microwave modulated optical carrier is generated by a high-speed EA-modulator designed for operation at 1.55µm. A low-power-consumption (50mW) transimpedance amplifier in MESFET technology on GaAs substrate is used for active impedance matching of the antenna and the modulator within the desired frequency range. The necessary power for the transimpedance amplifier is completely supplied by optical means using an NIR-laserdiode and a fiber coupled array of AlGaAs-GaAs photovoltaic cells.

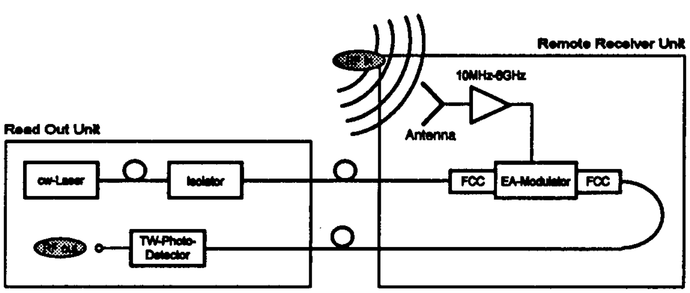

Figure 1: *Optical link for remote electromagnetic field sensing*

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Finite Ground Coplanar (FGC) Waveguide : A better transmission line

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Coplanar Waveguide (CPW) is frequently used in microwave and millimeter-wave integrated circuits (MMICs) because both series and shunt circuit elements may be easily integrated without requiring via holes. This eliminates the need for back side wafer processing and significantly lowers the fabrication costs compared to microstrip circuits. In addition, the shorter distance to the top side ground planes results in a smaller parasitic inductance than achievable with a via hole ground connection.

Several problems occur when using conventional CPW in practice though. Often, a lower ground plane is intentionally added for thermal dissipation, or it is inadvertently introduced by the carrier or package base. Along with the upper ground planes of the CPW on either side of the center strip, a parallel plate waveguide is created. Since the parallel plate waveguide supports a transverse electromagnetic mode with a lower phase velocity than the CPW mode over the entire frequency spectrum, energy leaks from the CPW mode to the parallel plate waveguide mode. When the circuit is cut from the wafer and placed in a package, the parallel plates create a rectangular box that supports resonances when the die size is $l_d/2$ in either direction where l_d is the wavelength in the dielectric. Of course, these resonances couple to the CPW and severely degrade the circuit performance.

To eliminate these deleterious effects, we have introduced a new transmission line called Finite Ground Coplanar (FGC) waveguide which is physically similar to conventional CPW but with electrically narrow ground planes. This maintains the favorable circuit layout characteristics of CPW but eliminates the parallel plate waveguide regions. Measurements and Finite Difference Time Domain (FDTD) analysis has shown that a ground plane width of twice the center conductor width is sufficiently large to maintain the low attenuation of conventional CPW. Furthermore, if the total line width is less than $l_d/4$, dispersion, radiation loss, and coupling to the microstrip mode is minimal. With these electrically small ground planes, this new transmission line is similar to a two wire transmission line.

Utilizing the electrically small ground planes for integration of passive circuit elements introduces new circuit layout possibilities. It is shown that elements placed in the ground planes add in parallel and behave the same as if the element were placed in the center conductor in the usual manner. Thus, MIM capacitors in the ground planes have twice the capacitance per unit length as capacitors in the center conductor. Furthermore, the parasitic reactance is approximately the same for both circuit layouts resulting in capacitors with a higher self resonant frequency when placed in the ground plane. Finally, the coupling between two adjacent FGC lines with a specified center to center spacing is reduced when the ground plane widths are reduced. This permits FGC to be used for highly integrated circuits and multichip module interconnects.

Low Cost Direction Sensitive Doppler Radar Sensors

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Millimeter wave sensor systems are key components in future intelligent transportation systems, inusrial process control and autonomous robot guidance. For many interesting applications (motion control, automotive ground–speed measurement, navigation aids), simple CW Doppler radar systems are sufficient. In millimeter wave radar front–ends, active integrated antennas lead to serious cost reduction. For low–cost CW Doppler radar sensors, self–oscillating active integrated antennas in self–mixing mode are the simplest sensor systems imaginable. Although CW Doppler radar sensors based on active antennas in self–mixing operation provide highly accurate speed information, no information whether the target is approaching or receding is given.

Classically, direction sensitive CW Doppler radar sensors are built by means of homodyne I/Q receivers. In these receivers, two mixers are employed. The LO signal of one mixer is phase–shifted about 90 degrees compared to the other. The IF output signals of the two mixers represent the I– and Q–component of the Doppler signal. From the phase shift between the I– and Q–signal of the Doppler signal, the sign of the Doppler frequency end hence the sign of the measured velocity can be deduced.

In this paper, we review several methods for measuring the velocity including direction information. Especially, we propose a method based on the homodyne I/Q receivers principle discussed above, which is excellently suited for active integrated antennas. To detect the velocity sign from the Doppler signals, two methods were implemented. At first, we tested a simple digital phase comparator IC as low cost solution. First experiments with this simple approach showed very promising results. Moreover, we investigated DSP based signal processing by means of complex valued spectral estimation techniques (complex valued Marple algorithm for parameter estimation in a AR–3 signal model). A comparison of both approaches will be presented.

Doppler Simulator for a Dual Frequency Near-Range CW-Radar

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The paper describes a new Doppler simulator which takes into account the antenna's near-field characteristic and serves to generate realistic signals from statistical surfaces consisting of randomly distributed scatterers. The signals can be used to predict the quality of the ranging and velocity information obtained by a dual frequency CW Radar-Sensor.

Self-oscillating Mixers in Automotive Radars

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Merging the primary feed antenna with the oscillator and the mixer is an attractive concept for near range radar sensors in cars. Chips are realized in SIMMWIC technology and operated in a self–oscillating mixer mode.

Transit time diodes are used as active devices in the 61 GHz chips. Originally the doping profile is optimized with respect to the output power. The chips provide an output power of up to 10 dBm.

Characterization of the minimum detectable sensitivity (MDS) and the Round Trip Loss (RTL) of the chips is done employing a new DC measurement technique. The I–V characteristics under oscillating and non oscillating conditions are measured and used to deduce a reliable quantity to evaluate the chip sensitivity. Compared to true RF measurement techniques this method is much more simple.

It can be shown that RTL can be optimized by proper design of the space charge regions in the transit time diodes. This is not the same design which yields maximum output power.

Self–oscillating SIMMWICs are used in a prototype radar for detection of turn–over and road conditions. Details of the system design and performance are given.

Session H01
Monday, July 13, PM 13:40-18:00
Room R02
Composite Materials I
Workshop on Complex Media and Measurement Techniques
Organisers : D. Jeulin, V. Vigneras
Chairs : G.W. Milton, D. Jeulin

Characterization of the Absorbent Properties of an Heterogeneous Material Containing Carbon Black Particles as a Function of the Process

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Composite materials have been manufactured by dispersing carbon black particles inside a thermosetting epoxy-amine polymer matrix. The final aim of the study is to put forward the relationship that exists between process, microstructure and absorbent properties at high frequency waves, in order to produce materials for furtive applications. The general effective medium laws are used to describe the evolution of dielectric properties with carbon black content at different frequencies between 2 and 18 GHz.

Two types of carbon blacks (Printex XE2 and Black Pearls 2000) have been compared in terms of conductivity and permittivity, all operating conditions being the same. An ultra-turrax, which is a rotor-stator stirrer with a high shear rate, has been used in order to obtain a dispersion of elementary particles as homogeneous as possible. All the experiments were carried out with and without surfactant. We could then determine the evolution of the dielectric properties with frequency and carbon black content.

It appeared that conductivity at steady state, and permittivity at high frequency waves increased with carbon black content. A conduction percolation threshold could be observed around 10wt% for Printex XE2 composites without surfactant, and around 14wt% for Printex XE2 composites with surfactant.

It is also clear that for equivalent carbon black content, Black Pearls composites are less conductive and have lower dielectric properties than Printex XE2 composites. Since Printex XE2 is slightly less conductive than Black Pearls 2000, this result should be linked to the difference in particle size.

The use of a surfactant decreases absorption and conductivity, but this influence is more significant for Printex XE2 composites. The surfactant provides a better adherence of the polymer matrix on the carbon black particle, separating these latter from each other.

Then, other materials with different microstructures will be tested. First of all, the reduction of mixing time, and/or the reduction of rotation speed will allow us to stop the carbon black erosion process before aggregates are separated into elementary particles. These long structures should reduce the percolation threshold, modifying absorbent properties. On the other hand, we intend to manufacture composites with an heterogeneous dispersion of carbon black. By mixing a free carbon black phase and a carbon black loaded resin, we will try to obtain an ideal microstructure which seems to give the best absorbent properties for a given carbon black content.

Prediction of the Effective Permittivity of Carbon-Black Polymer Composites from their Morphology

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Carbon-black polymer composites are made of a mixture of carbon aggregates (typically clusters of spheres with a 40-50 nanometers diameter) dispersed in a polymer. The ramification of these aggregates make easy the percolation of the carbon phase for a low volume fraction (typically for a few percents). From the size of the carbon particles, it is necessary to use the TEM (transmission electron microscope) to be able to study their morphology. To analyse the morphology of this type of material, we performed image analysis from micrographs obtained on thin slices (nearly 45 nanometers).

From a statistical study of the fluctuations of volume fraction at the scale of observations, the confidence interval of the measured volume fraction was determined as a function of the number of images (a 5% relative error is obtained from nearly 40 images). Then a model, based on the Boolean random set of spheres, was developed to correct the apparent volume fraction and two-point covariance function resulting from the effect of the thickness of specimens.

The morphological dispersion of carbon-black spheres in the polymer is modelled by a three-dimensional random set, based on a hierarchical Boolean random set combining multiple scales. Its parameters are estimated from the experimental covariance function. This model enables us to generate 3D simulations of the structure from which its percolation behaviour can be studied.

Finally, from the theoretical three point probability function of the model, we could predict the Milton-Bergman bounds of the complex permittivity of the composites ; from a parametric study of the model, we could suggest changes in the morphology to improve the performances of the material.

Local Scale Approach of the Complex Permittivity on a Carbon-Black Polymer Composite

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Physical properties of a material are generally measured at such a scale that they always are convoluted by the whole microstructure, i.e grains, second phases, grains boundaries, porosity, chemical heterogeneities... The prediction of the behaviour for a given material on the basis of a signal propagation (electromagnetic wave, thermal wave, electrical current...) through its microstructure is made a posteriori since it can only be compared and fitted to averaged macroscopic values. Furthermore, the exact role of any individual microstructural feature to be introduced in the prediction can only be speculated on since only few local data on a given property are available in the literature. As a consequence the improvement of a material performances is generally at best semi-empirical.

In opposition to such approaches, we have used a technique that allowed us to obtain quantitative local information on the change with frequency of the complexpermittivity of a carbon-black polymer composite, at various scales, including a few nanometers wide areas. The method is based on the study of the low loss region of an Electron Energy Loss spectrum recorded on a Transmission Electron Microscope. The complex dielectric function is drawn from the plasmon signal after an adequate numerical treatment. In addition to the possibility of probing the materials from a nanometer to nearly a millimeter scale, the microstructure can be simultaneously observed on the screen of the microscope and hence the local dielectric permittivity of a precisely selected microstructural feature measured with no convolution effect.

The material under considerations is a polymer in which 4% of carbon aggregates are dispersed. We could then obtain the dielectric information contained in a single carbon particle, in a carbon aggregate, a carbon aggregate and its polymeric environment, wider areas including clusters of carbon aggregates embedded in the polymeric matrix.
Results of the above analyses are presented through "Cole-Cole" diagrams which clearly show variations of the relaxation times of the electronic polarisability when different microstructural features are considered.
Completion of such multiscale measurements appeared to be an essential step for further achievement of real non-empirical predictions of the macroscopic behaviour for a given material.

Exact Solutions for the Dispersion Relation in a Wide Class of Periodic Media with Complex Moduli

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In the physics of heterogeneous periodic media it is rare to find exact solutions for the overall effective behavior. Here we will obtain exact solutions for the dispersion relation for a large class of materials with complex moduli. In periodic media where the dielectric constant is such that its Fourier coefficients vanish in one half of Fourier space we find that the dispersion relation is exactly the same as that of a homogeneous material. A related result is for the effective complex dielectric constant of a medium where the dielectric constant is analytic in the spatial coordinate z and bounded in the upper half z-plane (so that apart from constants the real and imaginary parts are Hilbert transforms with respect to z of each other). We find that such a medium is macroscopically equivalent to a medium where the moduli are averaged over z. This effectively reduces the problem to a two-dimensional one. Moreover if the dielectric constant of this new medium has a similar analytic dependence on the spatial variable y, one is left with a one-dimensional problem to solve.

Electromagnetic Study of Heterogeneous Materials Based on Integral Representation and Homogenization Methods

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Introduction

The last few years have seen a growing interest in the analysis of heterogeneous materials. These investigations lead to many applications as for example the developpement of absorbing materials [1] or frequency selective surfaces [2]. We can separate the different approaches used for the analysis of heterogeneous structures in two categories. The first one is based on exact models which describe accurately the structure. The second one uses homogenization methods to describe heterogeneous materials. Here we use both kind of methods. The exact model is based on a rigourous integral theory of gratings [3] and the second one is presented in [1]. We consider the study of a stack of infinite periodic gratings of lossy dielectric rods embedded in a lossless dielectric slab. This structure can be placed over a perfectly conducting plane for the analysis of absorbers or in the air for the conception of filters.

Models

The numerical solution of the integral representation of the electric field is obtained by means of a moment method for both TM and TE polarizations. The knowledge of the total field inside the rods allows us to calculate the reflection and the transmission (slab in the air) coefficients of the considered heterogeneous structures.
The equivalent homogenized model is a layered medium. The effective permittivity of each layer is obtained analyticaly. When the incident wave is TM, the effective permittivity is given by $\varepsilon^{*}_{effi} = d_i \varepsilon^{*}_{rods} + (1 - d_i)\varepsilon_{slab}$ where d_i is the density of rods in the layer i. For the TE polarization the equivalent medium is anisotropic and the effective permittivity is a diagonal tensor such as :

$\varepsilon^{d}_{effxi} \; d \; \frac{d_i}{\varepsilon^{d}_{rods}} \quad \frac{(d \quad d_i)}{\varepsilon_{slab}}$ and TThhT T Tlast h TTe T hTtfwy

Then we calculate the reflection and the transmission coefficients of the layered structure by applying the boundary conditions at each interface.

Results

First, we consider the case of photonic band gaps structures and compare our results, obtained from the exact model, with those presented in [2]. We analyse the influence of each parameter of the structure and we test the limitation of the simplified model based on homogenization for this kind of structure. Then we compare the performances in term of reflectivity of different structures.

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Scaling Theory for Homogenization of the Maxwell Equations

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Atificial (composite) materials with weak spatial dispersion are considered. By weak spatial dispersion we mean that the constitutive relations can include spatial derivatives of fields. Hence the relations may still be considered as local ones. It is the dependence on wavenumber k that is responsible for unique properties of the materials (chirality which is a first order in (ka) effect, artificial magnetism which is a second order in (ka) effect). Thus, we obtain a natural classification of constitutive relations in (ka) powers. Traditionally, one treats the relations in terms of multipole expansion.

$$< j >= c \,\mathrm{curl}\, M + \partial(P - \nabla Q) / \partial t \tag{1}$$

This bergs a lot of questions: the physical meaning of the vectors P and M, the dependence of the moments upon origin of frame, contribution of higher multipoles, etc.

We produce a scaling scheme of homogenization of the Maxwell equations basing on two mathematical formulae: the first one is a representation of any vector field in the form :

$$J_i \equiv \frac{1}{2} e_{ijk} \frac{\partial}{\partial x_j} m_k + \frac{1}{2} \frac{\partial}{\partial x_k} q_{ik} - \left(x_i \frac{\partial}{\partial x_k} J_k \right) \tag{2}$$

where

$$m_i = e_{ijk} x_j J_k \qquad q_{ij} = x_i J_j + x_j J_i \tag{3}$$

And the second one

$$\langle j \otimes r \rangle = \langle (\delta j) \otimes (\delta r) \rangle + (\langle j \rangle) \otimes (\langle r \rangle) \tag{4}$$

here $\vec{j} =< \vec{j} > + \delta\vec{j}$ and $\otimes$ means any multiplication operation e.g. calculation of m or q.

It has been shown that 1) A consequent introduction of high frequency magnetization demands taking account of quadrupole moment density. 2) Employing (2)--(4) permits one to introduce origin independent electric and magnetic dipole as well as quadrupole moment densities. 3) The constitutive equation (1) turns out to be exact. It does not include higher multipoles. 4) The suggested renormalization group procedure results in the usual Maxwell equations for macroscopic fields which, in the general case, differ from the mean fields

$$P^{(\mathrm{macro})} = \langle \ldots < P^l >_l \ldots \rangle_{L_h}$$

$$\mathrm{curl}\, M^{(\mathrm{macro})} = \sum_l \langle \ldots < \mathrm{curl}\, M^l >_l \ldots \rangle_{L_h}$$

$$\nabla \cdot Q^{(\mathrm{macro})} = \sum_l \langle \ldots < \nabla \cdot Q^l >_l \ldots \rangle_{L_h}$$

$$\left.\begin{aligned} B^{(\mathrm{macro})} &= c\, \mathrm{curl}\, S^{(\mathrm{macro})} + \nabla \cdot Z^{(\mathrm{macro})} + \langle B \rangle \\ \mathrm{curl}\, B'^{(\mathrm{macro})} &= c\, \mathrm{curl}\, S'^{(\mathrm{macro})} + \nabla \cdot Z'^{(\mathrm{macro})} + \mathrm{curl}\, \langle B \rangle \end{aligned}\right\}$$

here S and Z are alike to magnetic and quadrupole moments and are calculated in accordance with (3)

$$H^{(\mathrm{macro})} = B'^{(\mathrm{macro})} - 4\pi M^{(\mathrm{macro})}$$

$$D^{(\mathrm{macro})} = 4\pi P^{(\mathrm{macro})} + 4\pi \int \nabla \cdot \hat{Q}^{(\mathrm{macro})} dt$$

A systems of brackets denotes sequential averaging at different scales. A non-trivial moment is that $B^{(\mathrm{macro})} \neq \langle B \rangle \neq B'^{(\mathrm{macro})}$, $H^{(\mathrm{macro})} \neq B^{(\mathrm{macro})} - 4\pi M^{(\mathrm{macro})} \neq < B > -4\pi < M >$.

Examples are presented for artificial ferromagnetic as well as q-medium, that is a medium with significant quadrupole moment and vanishing P and M.

Modelling Impedance Spectra Results on Complex Dielectrics with Effective Media and other Models

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Impedance Spectroscopy (IS) is a powerful materials characterization method, which can be used to examine the properties of both homogeneous (e.g. polymers) and inhomogeneous materials (e.g. complex two phase dielectrics). In the latter case, IS also gives information about the microstructure of the material.

The usual directly measured property is the complex conductance Y*, but for low resistance samples this could be the impedance Z* (complex resistance), both as a function of frequency (usually from 10^{-2} to 10^{7} Hz). From these one can compute the other electrical properties, the admittance Y* (G_p+iωC_p), the capacitance C* (C_p-iG_p/ω), the impedence Z* (R_S-i(1/ωC_S) and the modulus M* (1/C_S+iωR_S), for the modeling of the results (here sub p and s stand for parallel and series equivalent circuit properties). The usual method of analysis is to plot the imaginary component against the real one (Cole-Cole or Niquist plots) for Y*, C*, Z* or M* and to use equivalent circuits to model the data (usually parallel RC combinations in series and parallel). Unfortunately the equivalent circuit model gives no direct volume fraction information. The other commonly used model is the simple cubic bricklayer model, with insulating mortar and conducting brick or visa versa, which is obviously incorrect in certain limits.

In this paper the results (i.e. simulated computer plots) obtained from effective media theories are examined to see if they agree with the formal microstructures for which the equations are strictly valid and to see to what extent the oversimplified bricklayer model agrees with equations derived from Maxwell's equations. The effective media theories examined are :
The Maxwell-Wagner (MW) model which describes spherical coated particles and agrees with the bricklayer model (cubic coated particles) for small (<0.01) volume fractions of one component but differs by 30 or more percent in the mid volume fraction range.
The Bruggeman Asymmetric Media (BAS) theory , which gives qualitatively similar plots, but with smaller Z* values than the MS theory with the same parameters.
The Bruggeman Symmetric Media (BSM) equation, which does not give the double arc IS Z_i against Z_r plots (representing information about the grains and grain boudaries) characteristic of the bricklayer, MW and BAS (coated particle) models, since the BSM equation describes a mixture of uncoated spherical particles. Lastly, a little known BSM model made up of coated and uncoated spherical particles is examined. In the limit of the coated particles filling all space, it is identical with the MW model, but unlike the others this model can describe three component systems, which will be further explored.

Fast Numerical Schemes for Computing the Response of Nonlinear Composites with Complex Microstructures

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In this talk, numerical schemes for computing overall response of nonlinear composites with complex microstructure are given. The schemes are based on an iterative proceedure proposed by Moulineq and Suquet [1], whereby one solves an auxillary problem with simple microstucture and relates this solution to the true solution using a series expansion for the Greens function. The method is versatile because it uses rectangular grids and the auxillary problem is solved rapidly with the use of Fast Fourier Transforms. The scheme can be utilized on a large variety of microstructures.

We give a scheme that converges at a rate proportional to the square root of the maximum contrast ratio of the media. We also discuss the use of multigrid based acceleration of the scheme, and give a simple method to compute the intergrid transfer operators required for the muligird method.

We give numerical examples of computed response for two and three dimensional microstructures and for linear and nonlinear materials.

Effective Field Method in the Problem of Electromagnetic Wave Propagation Through Media with Sets of Isolated Inclusions

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The effective field method is developed and applied to the calculation of the phase velocities and attenuation factors of the mean electromagnetic wave field in the matrix composite materials with sets of isolated spherical inclusions. The method is studied in wide regions of frequencies of the exiting fields, volume concentrations and properties of inclusions. The long and short wave asymptotics of the phase velocities and attenuation factors of propagating waves are obtained in the framework of the method and analyzed.

One of the advantage of the method is the possibility to take into account a spatial distribution of the inclusions in the matrix (background medium). The main aim of this study is to analyze the influence of the spatial distribution of the inclusions on the phase velocities and attenuation factor of the mean wave field in the matrix composite materials. The following statistical models of random sets of inclusions are considered :

- Boolean model, dead leaves model, Perckus-Yevic model, regular lattices of inclusions,
- Two scale Boolean model.

Information about random field of inhomogeneities that is used in the effective field method is contained in space correlation functions. The technique of the construction of such functions for the considered statistical models of random fields of inclusions is presented. Some general conditions are formulated and discussed for the correlation functions to obtain in the physically correct results for the effective phase velocities and attenuation factors of waves, in the framework of the effective field method.

The analysis of the considered models of space distributions of inclusions allows to investigate the area of application of the method , the sources and orders of the possible errors, the possibility to describe some fine properties of the composite media (the existence of optical or quasioptical branches of the dispersion curves, the region of anomalies of the behavior of attenuation factors, etc...). Some possible improvements of the effective field method are proposed and discussed.

Resonant Absorptions in Granular Silver Films near the Percolation : Experiment and Simulation using an Entropic Model.

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Granular metal films with low metal fractions exhibit the well known resonant absorption attributed to the excitation of surface plasmons in the metallic grains. This resonance is satisfactorily described by the Effective Medium Theories (EMT), like the Maxwell-Garnett, Bruggeman, or Ping-Sheng models. Close to the non-metal/metal transition, the morphology of the medium becomes more ramified, often fractal. The resonance is shifted and broadened and can no longer be directly related to the surface plasmon excitation in a cluster with given shape. EMT therefore fail in general to describe correctly this absorption around the percolation.

Some models were developed in oder to describe the optical properties of these fractal or ramified morphologies. A first class of models takes the disorder into account via a statistical description based, for instance, on the critical exponents of percolation. A second class of models uses directly the actual image of the morphology as given, for instance, by electron microcopy or atomic force microscopy. This second class (renormalization and entropic models) gives a better account of the optical properties of media which depart from random geometry.

We briefly recall the entropic model we have recently developed which is based on the calculation of local effective dielectric functions in the heterogeneous medium, at a characteristic size L_{opt} given by an entropic analysis of the disorder (following the information theory) in the actual image. These local dielectric functions are then self-consistently averaged on the basis of a partition of the medium between percolated and non-percolated cells of size L_{opt} .

We show that this model gives a good account of the optical properties of silver granular films around the percolation, prepared in our group by thermal evaporation under ultra high vacuum. In addition to the so-called plasmon resonant absorption in the metal clusters, the model predicts a weak absorption, on the edge of the main one, which we attribute to the hole resonance. To our knowledge, these two resonances were never simultaneously predicted by an optical model. This second absorption is effectively observed in some of our granular films close to the percolation and its position is correctly fitted by our model.

Combined models for the electromagnetic dependent scattering in dense heterogeneous media

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We address the problem of the electromagnetic properties of dense heterogeneous media composed of inclusions of size comparable to the wavelength. In the domain of visible light, this problem mainly concerns applications to paint, papers, but also the scattering by interstellar dust., with some extensions in the infrared and near ultraviolet. In the domain of microwaves, this is clearly the application to reducing the radar cross section of composite materials.

The problem consists in treating the scattering by a large number of spheres in strong interaction, i.e. dependent multiple scattering in a large sample. It has already been treated theoretically in the seventies by P.C. Waterman and by B. Peterson and S.Strom by introducing the concept of T matrix. In the ninetees, thanks to the progress in computer technology the calculation has been achieved by different groups : W.C.Chew, M.I. Mishchenko, Y.C.Tzeng and A.K.Fung.. The limit is now the capacity of the computers and the duration of the calculation.

In order to simplify the treatment of actual problems, we propose the concept of coherence volume, i.e. the volume in which the interaction between scattered fields has to be calculated in phase and amplitude. Outside this volume, because the loss of coherence, the problem reduces to energy interactions.

Using this assumption we have developed a mixed model in two steps :

- a local dependent multiple scattering calculation is performed inside the coherence volume, i.e. on a limited number of particles.
- a radiative transfer calculation (Four Flux model in this example) is then performed up to the size of the sample, by using the cross-sections calculated in the first step.

The diffuse and total reflectance and transmittance of the sample are eventually calculated.

The model has been applied to media with various concentrations.

The comparison of our model with a classical Four Flux model, as a function of particle concentration, allows to :

- estimate the exact size of the coherence volume
- fix the limit of validity of the Four Flux model
- evaluate the lengthening of the mean free path due to coherent interactions

J. I. P. R. 4 - Session I01
Monday, July 13, PM 14:00-17:20
Room 200
Basic Polarimetric Theory and Applications

Organiser : E. Krogager
Chairs : E. Krogager and Z.H. Czyz

Introduction to Fractal Theory

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The conventional decomposition from a distributed target is to seek a solution of average single target M^T, which preserves symmetry parameters A_O, C, and D, and a part which consists solely of non-symmetric parameters $B_O^T - B^T$, E^T, and F^T. These parameters with index T are determined easily from four equations.

The novel feature is to create a variable A_O^T in addition to the four non-symmetric target parameters of the old scheme. The new variable A_O^N extaracts out of the general symmetry-preserving A_O a special target variable A_O^T, such that $A_O = A_O^T + A_O^N$. The A_O^T now becomes part of the average single target parameters : A_O^T, B_O^T, B^T, C, D, E^T, F^T, G, and H. In this scheme C, D, G, and H, the target symmetry and coupling parameters, are still preserved intact. What is new in the scheme is A_O^T which before was A_O, « the generator and preservator of target symmetry ».

It is kind of ironic that the « symmetry-preserving » generator A_O itself is **not** preserved in the new scheme, but is split into A_O^T and A_O^N ! That was why this new decomposition took so long in coming to development.

The physical interpretation of the new scheme is a decomposition of the distributed target into a single average target M^T and an N-target (N here standing for non-symmetry) and a backround cloud of spherical particles. The C, D, G, and H still are preserved intact but the symmetry generator A_O is split, one part A_O^T contributing to the average single target M^T and one **new** part A_O^N (N stands for **new** here !) forms a background cloud of elementary **spheres.**

An exemple is shown consisting of a cloud of **dipoles** being averaged into a **single dipole**, a non-symmetrical N-target, and a **new background cloud** of elementary **spheres**, determined by A_O^N.

The new scheme extends the old scheme in cases where the old scheme breaks down.

The Expression of Reciprocity Conditions in Polarimetric Algebras

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Reciprocity is a long established principle in Electromagnetics. There are, however many distinct statements of this principle. In terms of the transmission of an electromagnetic wave between two antennas its practical application is extremely direct. In the scattering situation, when we come to consider matters from a polarimetric point of view, things are more complicated. To begin with, polarimetry introduces a layer of abstraction between fundamental theory and the representation of the scattering process. This allows a certain freedom of convention, essentially, how outgoing and incoming states are named and related. The IEEE convention on polarization states that an antenna transmits and receives the same polarization. Even so, there has been some debate in recent times concerning scattering conventins for polarimetric algebra which impact on the way the algebra interfaces between the physics and the formal conventions.

Clearly, it is important that the manner in which reciprocity is reflected in the algebra should be manifestly expressed. It is arguable also that it is desirable that this should be consistently and uniformly expressed.

In this paper we shall consider how reciprocity can be established rigorously in a polarimetric context. The reason that this is not entirely trivial is that the commonly accepted definition of polarization state, and indeed of the notion of scattering matrix, relies on a projection of the asymptotic field onto the wave plane in the far field region. In contrast, reciprocity as expressed, say, in the Lorenz statement, relates currents and voltages in the antennas. These, of course, relate locally to non-radiative as well as radiative fields, and the notion of polarization state cannot embrace such a full description. Although the concept of antenna effective length sidesteps this problem, it is not a wholly satisfactory answer as it merely displaces the conceptual difficulties.

While, in the longest established framework of polarimetric algebra, reciprocity is associated with symmetry of the backscatter matrix, it is germane to ask how polarimetric algebras should generalise to less special cases. In particular there are two important generalisations to consider. One is the case when a scattering measurement takes place in a non-reciprocal medium, for instance one exhibiting faraday rotation. Another is the bistatic scattering case, where reciprocity may still hold, but symmetry in the scattering matrix does not generally obtain.

With these topics in mind, we examine how a number of modern polarimetric representations move between the special and general cases.

Utilization of Phase Related Information in Radar Polarimetry

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In the simplest form, the utilization of polarimetric radar data relies only on the magnitudes of the elements of the complex, symmetric Sinclair scattering matrix. However, thereby the coherent structure of the data is ignored, and the useful information contained in the phase relations is lost.

Indeed, it takes more efforts to fully utilize the information contained in the phases. First of all, an accurate calibration is required in order to compensate for system imperfections and other disturbances, but in addition, more sophisticated processing techniques are required. The foundation and formulation of such techniques is a subject of significant current interest and research, because different approaches and views are being employed and evaluated. This does not necessarily mean that one approach is superior to others, but it means that there is a need for clarifying the advantages and limitations of different approaches in different contexts. In addition, the combination of polarimetric and interferometric techniques represents a new, challenging field of research in radar polarimetry.

Following a brief overview of the basic formulations used for the utilization of phase related information in radar polarimetry, the paper will touch on such issues as absolute and relative phases, uniqueness, interference, and phase considerations for distributed targets. The relations between theories and the actual physics of targets and systems must always be kept in mind, and should, ultimately, form a basis for resolving disputes and ambiguities on these matters. Therefore, due attention will be paid to practical aspects and physical significance of the methods considered.

Theoretical Results of the Bistatic Radar Polarimetry on Canonical Targets

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In the 50's, Sinclair proves that the polarisation state of a scattered wave depends on the polarisation state of the transmitted wave but also depends on the target. The monostatic radar polarimetry theory appears and the modification of the polarisation state of the transmitted state is modeled by the complex scattering matrix. This matrix relates the transmitted and the received Jones vectors of the waves. In the monostatic configuration, the scattering matrix has the property of being symmetric, but it is no longer true in the bistatic case. For that matter, the bistatic scattering matrix is broken down into a sum of 2 matrices : a symmetric one and a skew-symmetric one.

A wave can also be defined by its Stokes vector. The real Kennaugh matrix relates the transmitted and the received Stokes vectors. Huynen expresses the monostatic Kennaugh matrix, which is symmetric, in function of the Huynen parameters. Each of these parameters is linked to a specific physical characteristic of the target. Because the phase relative backscattering matrix contains only 5 totally independent entities, the 9 Huynen parameters are related to each other by the 4 independent monostatic target equations. In the bistatic case, the polarimetric dimension of the target is equal to 7, the Kennaugh matrix is then described by 16 parameters. We defined the 7 new bistatic parameters, in such a way as keeping the Huynen parameters and we especially defined the 9 independent bistatic target equations which link the 16 bistatic characteristic parameters of the measured target.

In addition to the 9 bistatic target equations, the polarisation fork on the Poincaré sphere would allow a better recognition of the polarimetric target signature. At first, the characteristic polarisation states of the target have to be stated, then they have to be located. In the monostatic case, they amount to 8. The polarisation states O_1, O_2 and X_1, X_2 cancel the copolarised, and the crosspolarised scattered power, respectively. C_1, C_2 and D_1, D_2 maximise and minimise the crosspolarised scattered power. The number of characteristic polarisation states amount to 16 in the case of the bistatic polarisation fork. The 8 additional points are K and L, which maximise and minimise the copolarised scattered power, E_1 and E_2, which are the eigenpolarisation, M and N the transmitted polarisation states for maximum and minimum scattered power, M'' and N'' the received polarisation states for maximum and minimum scattered power. The characteristic polarisation states M, N, M'', N'' are obtained from a singular values decomposition of the bistatic scattering matrix. All of the other polarisation states are obtained by minimisation and maximisation of either the copolarised scattered power, or the crosspolarised power versus the Deschamps parameters 2g and 2d. Now, this bistatic radar polarimetry theory is put into practise with some complex scattering matrices obtained by simulation. These matrices specify the scattering of some canonical targets like sphere, dihedral and trihedral. The evolution of the 16 bistatic parameters is studied, but also the bistatic target equations. Then, the knowledge of the bistatic polarimetric signature of several canonical targets is improved owing to the bistatic polarisation fork.

On the Importance of Utilizing the Poincare Sphere of Tangential Phasors as Two-Folded Riemann Surface in Radar Polarimetry

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Tangential phasors on the polarization sphere represent polarization and phase (PP) unit vectors. The polarization is determined by the point of phasors' tangency on the sphere. The phase is given by the direction of the phasor, and the change of phase is equal to one half of the angle by which the phasor's direction is being changed. Such a sphere of tangential phasors can be treated as a two-folded Riemann surface with each point of tangency considered as a branch point of the surface. The most advisable, for its ease to manage, the orthogonal null-phase (ONP) PP basis is being formed by two collinear phasors tangent to the sphere at its antipodal points. (For instance, circular basis proposed by the IEEE standards does not correspond, unfortunately, to the collinear phasors.) Phasors are especially useful for determination of such bases. Different orientations of bases' phasors, denoting choices of bases that are different, most spectacularly demonstrate the dependence of matrix elements on the phase of bases' vectors. In polarimetry, there is especially important to realize that the orthogonal bases depend not only on their polarizations but also on the basis vectors' phases, that is, on basis phasors' directions. Canonical forms of bistatic scattering matrices can be obtained by rotation of the original horizontal/vertical linear polarization basis on the PP sphere by three Euler angles, three of them denoting change of phase, that is, change of their phasors' direction. Phasors used as upper and lower indices of the PP column vectors, and lower indices of scattering matrices, ensure simple and easy to remember forms of vectors' and matrices' transformation formulae under the PP sphere or its basis rotation. Using phasor indices also simple formulae can be presented describing vectors' and matrices' transformation under reversing the propagation z-axis by rotation of the local spatial xyz coordinate system. Such transformation of the PP vector of an antenna is equivalent to its reversal by rotation versus the z-axis direction. That way, for example, one-way transmission between two antennas can be presented as a 'scattering by the free space' with reversal matrix used as a Sinclair scattering matrix (i.e. amplitude scattering matrix in the BSA - backscattering alignement). Such 'two-way transmission equation' spectacularly demonstrates fulfillment of the reciprocity requirement. Using coordinate system reversal also different mutual dependencies can be established between Sinclair and Jones or Kennaugh and Mueller matrices in different ONP PP bases. This is of an utmost importance for instance in the analysis of the cascading matrices of the polarimetric two-ports. Such an analysis starts with consideration of a five-parameter scattering matrix of the whole two-port with its transmittance Sinclair or Kennaugh matrix in the simplest, canonical form obtainable in the 'characteristic' ONP PP basis. Then the transformation of the matrix is required from its characteristic basis to a commonly used linear or circular one, and another transformation: under the output z-axis reversal leading to the Jones or Mueller transmittance matrix.

Phasors can also be added up or multiplied on the PP sphere. That corresponds to addition and Hermitian multiplication of their PP vectors. Multiplication represents, for example, reception of polarized wave by polarized antenna resulting in complex value of the received voltage. Phasors to be multiplied should be given a propagation upper index, plus or minus. Such an index does not influence on phasors' value. It indicates only the orientation of the wave or antenna along the axis of propagation in its positive or negative direction. If the phasor represents a wave, it can be considered as rotating in time with the 2ω angular speed in the clockwise or counterclockwise direction depending on its propagation index. Then, if its rotation is in the direction of an antenna phasor, the phase lag of the received voltage takes place. It is equal to one half of an angle between the two phasors, shifted parallel to one point along the great circle arc through the points of tangency. The opposite direction of rotation means phase advance of the received voltage. Magnitude of the voltage equals cosine of one half of an angle between the two polarization points. Any phasor can easily be decomposed into linear combination of any orthogonal collinear phasors. What one should remember only is the rule of multiplication of phasors with different propagation indices.

Addition of two tangential phasors on the polarization sphere requires to find a specially chosen small circle through the two points of tangency. Rotation of the sphere together with one phasor, about an axis through the center of that circle, should cause the moving phasor to cover the other. Then, a wanted sum will be also covered by the moving phasor. If both phasors represent vectors of equal magnitude, their sum will be at half a way between the two phasors being added.

On a Phenomenological Model Choice of Waves Scattering by Complex Radar Targets : Comparison of Simulation Data and Polarimetric Measurements Data

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There is an opinion that obtaining as much as possible information about objects' scattering properties by polarization techniques is the sufficient condition for successful solving of many practical tasks in radar polarimetry. Thus, one can miss that the ultimate goal of designers of civilian and military polarimetric radars (PRs), intended for mass production, is not to obtain maximum polarization data at any cost, but to ensure the given performances of the system to be developed. Therefore, during PR development designers try to find a compromise between available desire to extract all potentially attainable information from received signals and to achieve a minimal cost and technical complexity of the polarimetric radar.

In this connection, the researches, concepts and notions being used like a theoretical base by those experts, who are directly engaged in designing and development of polarimetric radars, have a large significance. The practice has shown that super-complex theoretical findings in radar polarimetry field have a very few chance to be realized in reality. As a rule, only those theoretical researches or physical processes models are well perceived, which get in a resonance with a practical experience of the experts and their intuitive representation about a nature of the observable phenomena.

During many years, the "point target" concept was the basic concept in radar and, hence, in radar polarimetry. Thus, one of the widespread criterion of target's "pointness" was the requirement that the incident wave's propagating time along the scattering target should be much less than the radiated signal duration.

In practice, the relative dimensions of radar targets can be much less than the resolution cell dimensions of real aperture radars, but, in the same time, their physical extension can exceed the wavelength many times. For example, in X-band physical extension of targets of interest will be hundreds (thousands) times as large. If, neglecting this fact, radar targets will be considered as "point" objects having stable in time backscattering properties, than, sooner or later, essential problems caused by this model constraints will arise when solving the detection, selection, identification and classification problems through use of polarization information. The understanding of this feature has resulted in occurrence of investigations, both in Russia and abroad, connected with development of more adequate models describing the backscattering of complex objects.

This paper purpose is to compare the results of simulation made by the author (with use of two phenomenological models of waves backscattering on complex shaped bodies) with experimental data of polarization parameters measurements of extended targets, and also estimate the adequacy of both models to the real data. The results of one of the basic Russian works in this area [1], and also some results of the investigations in co-authorship with Prof. Tatarinov V.N. [2], [3] were used as initial premises for the given research.

In the paper, simulation results of temporal samples of polarization parameters concerning the phenomenological model of "local sources" [1] and well-known "bright points" model are given. Among the analyzed experimental data, results of measurements of complex shaped targets' polarization-energetical indicatrices, which supplement the data presented earlier in [4], are used.

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Entropy and Polarization of a Stochastic Radiation Field

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Much of the existing literature on the theory of radiation field is restricted to energy considerations. In this paper, theoretical ideas emphasizing the achievements in classical electrodynamics and numerical results concerning the entropy of a radiation field are discussed. Special emphasis of these calculations is given on the effect of polarization. The geometrical feature (Stokes vector space formulation) that emerges is presented along with a thermodynamical analysis underlying the two-level description of a partially polarized wave. As an illustrative application of our analysis, we consider elastic multiple scattering of light by a dense random collection of dielectric spheres and analyze the behavior of entropy production during the irreversible evolution of the state of polarization. Computational techniques, based on Monte Carlo simulations provide a useful tool for studying multiple scattering of light by a spatially random medium composed of uncorrelated spherical dielectric particles. In a medium containing particles small compared to the wavelength (Rayleigh regime), the characteristic length of depolarization for incident linearly polarized light is found to exceed that for incident circularly polarized light, while the opposite is true in a medium composed of particles large compared to the wavelength (Mie regime). These numerical results are compared against measurements on suspensions of polystyrene latex spheres in water. One of the most remarkable aspects of this problem, where no energy exchange between radiation and scatterer takes place, is that the stationary state corresponds both to the state of minimum production of radiation entropy and to the state of maximum entropy.

New Contemplations on Polarimetric Decomposition Based on Expected Target Orientation

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This presentation deals with the aim of polarimetric target classification based on the complex Sinclair scattering matrix without incoherent averaging to handle randomly fluctuating characteristics as one important radar task for the implementation of polarimetry.

Starting from considerations on surface scattering it is shown that realistically structured targets usually do not include helical reflection parts, which essentially depend on phase differences and are therefore sensitive to measurement errors. The majority of man-made as well as natural targets generates reflection parts with predominantly vertical or horizontal orientation.

From this follows a preference in decomposition for target classification concerning discrimination between horizontal/vertical and diagonal orientation besides the distinction between odd and even numbers of multiple reflections. A correspondingly new way of target decomposition into a trihedral, a horizontal or vertical dihedral and a +or-45ø dihedral is presented and interpreted, different from the known proposals of Krogager e.a., which are based on Pauli spin matrices, rotation symmetries and basis invariant target features after Huynen.

Large convex as well as small concave target surfaces including trihedral and dihedral corners contribute in a much stronger way to the radar cross section resp. scattering matrix than any edge or tip does. This reduces the capability of discrimination between horizontal and vertical orientation in polarimetry, which is explained by some basic target models and by results from SAR measurements.

On one hand each kind of target classification demands potential high resolution in three dimensions for minimizing the number of reflection centers within the radar cell contributing to the mutually interfering reflections from the target surface. On the other hand interferences from few reflection centers lead to increasing fluctuations in amplitude, phase and direction of the common focal point also with small aspect changes or short time intervals and by this multiplicative noise yield a reduction in the classification capabilities via an estimation of the scattering matrix. High resolution by very high frequencies or small radar cells with pulse compression in range and synthetic aperture processing in azimuth combined with the natural resolution in elevation based on the target location in each case is necessary for decomposition purposes.

Any decomposition based on the complex scattering matrix a priory demands compensation of motion differences between radar platform and target which can be fulfilled with modern SAR processing in combination with inertial navigation and global positioning.

This proposed way of decomposition is also in agreement with considerations on the optimum choice of the polarization basis to cope with errors in polarimetric measurements from channel differences and insufficient motion compensation or if just parts of the polarization matrix are measured in half-polarimetric systems for reasons of cost expense.

Finally further influences and possible compensation methods are discussed caused by the antennas if targets are observed at off-broadside directions and by the target aspect in elevation respectively depression angle which can be handled to some extend analogously.

Session J01
Monday, July 13, PM 13:40-16:40
Room 450
Remote Sensing in European Union Projects

Organiser : D. Solimini
Chairs : D. Solimini, G. Elgered

SNOWTOOLS
Research and Development of Remote Sensing Methods for Snow Hydrology

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This paper describes the general framework, the aims and the organisation of the SNOWTOOLS project, with emphasis on the role of remote sensing.
The objectives of the SNOWTOOLS project is to develop generic methods for the correction and interpretation of optical and microwave data with the main aim of generating high-level products and improving the extraction of information specific to snow hydrology from these data. The start of the three years project was October 1996, and is supported by the Commission of the European Community, Environment and Climate programme and end users.

The project has established close links with the user community represented by water resource management authorities, meteorology institutions and hydropower production companies, who have been strongly involved in the specification of high-level snow hydrology products.

The user-derived specification for high level snow products has been used to identify electromagnetic snow signature data gaps, required preprocessing algorithms to be implemented and to define necessary improvements in existing hydrological models. Electromagnetic signature gaps will be filled by updated information from dedicated field experiments using radiometers, scatterometers and ground-based sensors. By combining these data with snow structural measurement the development and validation of respective electromagnetic models will be performed, which also will take into account the effec□□of surface tilting and limitedÿÿky solid angle.

The models will be used in the evaluation and development of generic satellite multisensor classification algorithms.

- Two dedicated remote sensing experiments, one for mountainous basins and one for boreal basins, are carried out for both the development and validation of the project. The "HBV model" has been chosen as a candidate for enabling the optimal utilisation of remote sensing data. The performance of the developed generic methods will be quantified and evaluated by the end users. At present some of the conclusions from the work are:

- Steered by the snow product specifications, the algorithms to be developed have been identified.
- The product "snow covered area" using active microwave data requires a radiometric accuracy better than 0.5 dB.

- The influence of the underlying ground on the microwave snow signature is very important. The existing experiments tend to concentrate only on the snow, and little attention is given to the ground.
- Many of the campaigns are concentrated on only one snow situation.

The mountain basin field campaign in 1997 have established a multi-temporal/sensor dataset for algorithm development. In the first year, the mountain basin campaign focused on the acquisition of ERS and RADARSAT data combined with optical data.

Early Warning and Long-Term Monitoring of Volcanoes Using Synthetic Aperture Radar Interferometry (InSAR)

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Volcanoes deform in a gross and permanent way as new material is deposited (e.g. lava flows) and in a more subtle (centimetres to meters), and slow, manner in response to the movement of magma or to crustal relaxation associated with lava field emplacement or dike intrusions. Monitoring of ground deformation is one of the most important techniques for the forecasting of eruptions. Until now, volcano deformation has been monitored firstly by precise surveying methods, in which benchmarks distributed over the volcano are regularly measured, and secondly by continuously monitoring instruments like tiltmeters or strainmeters. The EU project MADVIEWS (Monitoring Active Deformation of Volcanoes by Interferometry as an Early Warning System) is aimed to test out on Etna volcano (Sicily) the Interferometric Synthetic Aperture Radar (InSAR) technique. This technique provides a dense and homogenous picture of the deformation than cannot be obtained by ground techniques. In addition, it is almost independent of weather, access or danger. The main goals of the project are:

1. Study of the coherence of InSAR images and their relation with environmental parameters.
2. Study of the propagation artefacts due to troposphere and the ionosphere.
3. Capability assessment of InSAR for DEM generation and improvement.
4. Use of InSAR for the determination of volumes of lava flows.
5. GPS and other geodetic ground control of the deformations detected by InSAR.
6. Overall assessment of the present capability of InSAR for volcano monitoring.

Eufora : European Forest Observations by Radars

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The past seven year have seen the deployment of five spaceborne SARs systems: ERS1, JERS1, ERS2, SIR-C/X-SAR and RADARSAT. Also, ASAR on board ENVISAT will be launched early 2000. Thus, SAR imagery has been available on a continuous basis.

Increasing research activities have shown that SAR can have a major role among remote sensing techniques to observe and monitor forest covers. However, despite such promise, SAR are still underused. Hildrances to the use of SAR data in forest applications include the difficulty in understanding the information content of SAR data with respect to forest observation requirements, and the lack of appropriate analysis tools to meet the requirements.

In this context, EUFORA has been proposed to the Environment and Climate Programme, as a methodology research project, to theme 3 "Space Techniques applied to environmental monitoring and research".

The project aims at a) evaluating the most advanced radar remote sensing research results with respect to forest information required in environment and climate studies and in forest management operations, b)validating methods and results in different European sites, in order to define methods that can be used in European conditions.

Three axes of research are being developed in order to draw conditions about the effective use of SAR data for forest mapping, forest change detection and forest parameter retrieval:

- Comprehensive analysis of radar measurements over forest areas: the measurements include current spaceborne SAR data on different European test sites, experimental airborne data provided by EUFORA campaigns conducted in Finland using HUTSCAT scatterometer and Carabas VHF SAR, and in France using HUTSCAT,
- Modelling of the radar backscatter: different modelling approaches are tested. The result will lead to an improvement of the backscatter models to interprete different data sets both in intensity and in phase, acquired in different forest conditions,
- Algorithm development: robust methods of wide applicability , as verified in the EUFORA study sites, are seeked. The methods include identification of forest type or forest parameter discriminators from SAR data, and SAR data analysis methods to extract them.

The paper will present the objectives, approaches, the work completed and a summary of results, in terms of both research and applications.

European Radar-Optical Research Assemblage (ERA-ORA)

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The general objective of this concerted action is to improve the radar data analysis and utilization tools developed by European researchers for Earth observation from space.

Radar is sensitive to environmental parameters, like soil moisture and roughness, vegetation type and biomass. However, the exploitation of radar potential in environmental applications has been hindered by the fragmentation and particularization of model and application tools and by the restricted amount of experimental data at the disposal of a single researcher. This project strives to enlarge the available research tools by joining different sets of experimental data and theoretical models.

A pool of European researchers will put in common validated radar data (with corresponding ground truth) and the eventually available simultaneous optical/IR measurements, and computer programs for theoretical backscattering modeling. A virtual Distributed Library (DL) will thus be organised, implemented and made electronically accessible to the participants and subsequently to the open scientific community.

. One section of the DL will include radar data taken over land (bare soil, crops, forest and snow-covered terrain), i.e., backscattering coefficients for several agricultural and forest sites and one snow-covered site in Europe. For some sites, also simultaneous optical/IR reflectances will be available. All radar signatures and optical reflectances are accompanied by significant ground data (soil moisture and roughness, vegetation biomass, leaf area index, snow water equivalent, etc.). A second section of the DL will assemble different theoretical models for backscattering simulation.

A coordinated use of data and models stored in the DL will be subsequently organised with the following objectives:

- To assess the enhancement of sensitivity deriving by a synergistic use of different instruments and/or techniques, like radar and optical/IR data, multitemporal and multifrequency/multipolarization techniques, interferometric and multifrequency/ multipolarization techniques;

- To improve the modeling accuracy and to devise and develop retrieval procedures to estimate soil moisture, agricultural biomass, forest biomass and snow water equivalent;

- To define efficient radar/optical configurations leading to a sufficient retrieval accuracy for selected environmental applications.

The *Stardom* Concerted Action

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With the successful mission of ERS-1 and the planned launch of ERS-2 and ENVISAT, Europe has an unique opportunity to use satellite data for operational monitoring of the marine environment.

The objective of the present concerted action STARDOM (Space Techniques Applied in Research and Development of Ocean wave Monitoring) is to federate actions and to bring together scientists to further improve space technique measurements and operational use of the two-dimensional surface wave spectrum into numerical wave forecast models. Such a goal have been identified for a long time as a pressing need for navigation and maritime industry as well as for advancing in our knowledge of the ocean-atmosphere interface and the quantification of the overall influence of waves on the climate system.

Within such a framework, the main tasks and specific objectives of this concerted action are as follows:

- To improve our quantitative knowledge of imaging mechanism of ocean waves for application to ocean-instrument spectral inversion (that is, in deriving directional properties of the ocean wave field from a spaceborneinstrument i.e.Synthetic Aperture Radar and/or Real Aperture Radar witha rotating antenna) ;

- To improve our quantitative knowledge by means of numerical andexperimental studies of the interaction between electromagnetic wavesand the ocean surface ;

- To coordinate and to define field experiments to prepare future satellite missions ;

- To develop a strategy to better analyse and to assimilate satellite data into numerical wave models.

Progress on Advanced Weather Radar Techniques in the *Darth* Project

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The DARTH project (Development of Advanced Radar Techniques for Hydrometeorolgy) addresses a number of problems encountered when one tries to use weather radars for quantitative purposes and storm diagnostics. The project involves the research collaboration and exchange of data between research and operational weather radars of our partner institutions across the EU and aims to evaluate methods of enhancing the information retrieval applicable to current and future systems.

Many current operational radars in Europe now have doppler processing, and some also have polarization diversity; C-band is the preferred wavelength for operational purposes. From previous experience of such data it was already apparent that extended capabilities reveal in the first instances particular problems which were formerly difficult to quantify. In particular, whilst it was often supposed that, at C-band, attenuation was not a very serious problem, polarization diversity with ZDR measurement reveals strong gradients in differential reflectivity in severe storms. In such cases it can be inferred that absolute reflectivities are affected by strong attenuation and consequent underestimation of rainrate. The capabilities of ZDR in aiding the detection of hail are also under investigation.

Although the most advanced of the current operational radars offer only differential reflectivity in the way of polarization capability enhancement, modern signal processing techniques allow further enhancements without extending the radar hardware complexity to any great extent. The polarization agile DLR C-band 'Poldirad' radar has the capability of being configured in many different ways to explore such issues as the optimum polarization basis, and, in terms of its time-series recording capabilities, offers the opportunity for simulating radars of linear, H/V and slant as well as circular polarization modes in which the signal correlations may also be evaluated. These capabilities are being exploited in the project to compare, on short elapsed timescales, the performances of various measurement strategies. In this respect, the variations in apparent data signatures with respect to propagation effects reveals significant differences. Propagation effects are revealed in a very striking way when bases other that the linear H/V are used. The question then arises as to whether, having registered the presence of propagation effects, anything sensible can be done with them. When the radar basis polarizations are clearly non-aligned with the propagation eigenpolarizations of the precipitation medium - normally close to horizontal and vertical - there is potentially useful information in the cross-polar signatures of the target medium. Earlier work at S-band showed that it was relatively easy to extract the differential propagation parameters using such information. At C-band, this task is more complicated, owing to the wider parametric variation of the differential back-scattering parameters of the target medium. Such quantities are quite sensitive to assumed drop-size distribution, for example. To overcome such difficulties, we are looking to construct suitable invariants from the observed correlation data, so reducing the model dependence in the extraction of key propagation constants.

Another, and entirely different, propagation mechanism that impacts many weather radars is clear air anaprop. Failure to identify anaprop effects can lead to erroneous observations of precipitation. Whilst doppler filtering affords a considerable level of success in discrimination against this type of clutter, it does not provide a complete solution, and in cases where the doppler velocity is non-zero, such as from sea-waves particularly, may be of limited help. One of the objectives of DARTH is to apply simulations of anaprop to help identify more clearly areas of the radar image which are so affected. The emergence of limited area numerical weather prediction models is one way of generating a model of the radio refractive index profile from which propagation, and in particular, ducting, can be predicted and which is being explored at present.

MEFFE - Meteorological Foresting for Flood Events

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This EC project aims at improvements in rainfall intensity estimates for mitigating the risk of flood events using nowcasting and remote sensing techniques (meteorological satellite, combined satellite-radar-data and numerical models).

The main object of the project is being achieved by :

- Better knowledge of meteorological systems generating different flood events
- Coupling satellite data, radar data and numerical Limited Area Models
- Improving MW and Vis-IR algorithms for precipitation retrieval
- Improving weather numerical models (LAM and Cloud Mesoscale Models) that combine surface and upper air measurements, and radar-satellite data
- Defining the characteristics of Nowcasting procedures for rainfall rate intensity.

The project brings together the expertise of groups working on satellite passive sensors (FISBAT-CNR Bologna, Italy; IFA-CNR Rome, Italy; MAX PLANCK Institute for Meteorology METEOROLOGY Hamburg, Germany; AEROSPACE RESEARCH ESTABLISHMENT Koehn, Germany) and groups of radar meteorologists (RATHERFORD APPLETON LABORATORY, Didcot, UK; IAS-JOANNEUM RESEARCH Graz, Austria; DLR Munich Germany).

The remote sensing estimates of precipitation patterns is a key issue for establishing very short range rainfall forecasting techniques. In particular there is a need to give reliable input data for initializing runoff models in terms of precipitation over basins, river catchments and regions of particular hydrological characteristics, to forecast and prevent rainfall induced disasters. Meteorological radars and a variety of satellite sensors have been applied since many years for rain areas delimitation, gradually replacing conventional ground rainfall measurements. The remote sensing Instruments don't provide direct rainfall measurements at the ground, but they measure physical quantities that are to be interpreted in terms of precipitation. Laws to infer precipitation from remote sensed data are investigated to formalize the dependence of the sensors responses upon the rain at the ground. To establish the correlation between radar reflectivity, satellite radiance and precipitation a knowledge of the cloud system and its response to sensors wavelengths is also needed. Intensive experimental studies have been carried out about typical cloud systems.

The results obtained in the first two years of MEFFE (which started May 1st, 1996) will be presented by the co-ordinator.

The WAVEFRONT Project : Ground Based GPS Meteorology in Europe

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The WAVEFRONT project is a collaboration with partners in four European countries and is supported by the EC Environment and Climate Program. The project started in September 1996 and lasts for three years. The aim of the project is to develop the technique of using signals from Global Navigation Satellite Systems (GNSS) to measure the variations in atmospheric water vapour above receivers on the surface of the earth. The Global Positioning System (GPS) is the presently dominating one and is used in the project, even though future activities may very well also include other satellite systems.

Comparison experiments between data from microwave radiometers and GPS typically give agreements in the range 1-2 kg/m^2. Transportable radiometers have been used together with permanently installed radiometers and GPS receivers. One experiment was carried out in the area of Madrid, Spain, and the other at Onsala on the Swedish west coast.

Three different software analysis packages using identical GPS input data are evaluated: (1) the Bernese software developed at the University of Berne, (2) the GAS software of the University of Nottingham, and (3) the GIPSY software from the Jet Propulsion Laboratory. We investigate the impact of using different networks in terms of size and shape, different statistical parameters in the models, and different elevation cut-off angles for the GPS observations.

We will give the status of the archive of estimates of the water vapour content at about forty continuously operating GPS sites in Europe. The archive consists of GPS estimates of the water vapour content as one hour averages. The results from this project will be a two year long time series.

GPS data also have a potential for the improvement of weather forecasts. Therefore, near real-time applications as well as a study of the possibilities to estimate the three-dimensional distribution of water vapour are described. The critical parameter for near real time operation is the accuracy of the orbits used for the satellites.
Both postprocessed and forecast orbit parameters have been evaluated.

Session K01
Monday, July 13, PM 13:40-17:00
Room J
Remote Sensing of Atmosphere

Organiser : N. Pierdicca

Chairs : N. Pierdicca, N. Kaempfer

Microwave radiometric retrieval of atmospheric temperature profiles by using temporal and spatial correlations

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Usually microwave radiometric retrievals of atmospheric temperature profiles suffer of inadequate vertical resolution and accuracy when compared to radiosonde derived profiles. The development of Kalman filtering based retrieval algorithms, that are able to exploit statistical information and suitable evolution models for the atmospheric variables, can help overcoming the mentioned limitations.

In this paper we have considered the determination of temperature profiles over the Italian area from satellite- and ground-based radiometric measurements. The available database of atmospheric profiles for the development of the inversion algorithm consisted of about five years of radiosoundings, released four times a day, at six stations (Milan, Udine, Rome, Cagliari, Brindisi and Trapani) distributed over all the territory. From this data set we computed mean values and covariance matrices for profiles belonging to each station, and studied the temporal correlation, as well as the spatial correlation among different stations.

The corresponding radiative database was computed by means of the Liebe's model, simulating satellite-based measurements, for the atmospheric sensing channels of SSM/T (54.35, 54.9, 58.4, 58.825 and 59.4 GHz), and ground-based measurements at two water (vapor and liquid) sensing channels (23.8 and 31.65 GHz) and three temperature sensing channels within the 60 GHz O_2 absorption complex (53.85, 55.45 and 57.97 Ghz).

On the basis of the geophysical and the radiative databases we have developed a Kalman filtering algorithm, suitable for processing different sources of measurements: a ground-based continuously working profiler, satellite measurements available at each satellite pass, and radiosonde profiles released at specific times from nearby stations.

The development of the evolution models needed for the implementation of the Kalman filter, and the assimilation of measurements performed at different times and locations were obtained both by exploiting the empirical time and space correlations deduced from the geophysical database, and by suitably adjusting the parameters of a geostatistical prediction method like the kriging estimator.

The algorithm described above has been applied to SSM/T data acquired over Italy and to the first measurements of a ground-based radiometer located in L'Aquila, about 100 Km East of Rome.

Finally, we have compared the accuracy and the robustness with respect to measurement errors of the algorithm, towards the performances of more conventional linear regression algorithms.

Numerical Simulations and Aircraft Measurements of Melting Layer Effects on Microwave Emission and Scattering of Stratiform Precipitation

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The basic forms occurring in most precipitation systems are generally of two types, stratiform and convective. Both types are widespread in time and space and may occur in different regions of the same storm. In stratified precipitation the hydrometeors fall to the ground almost from or near the top of clouds and this layer is mainly composed of snow and melting snow, while in convective precipitation updrafts are so strong to carry the growing particles upward until they become heavy enough to overcome the updraft and begin to fall. Stratiform precipitation represents a large portion of total precipitation, especially at tropical and mid latitudes.

Generally speaking, the main difference between a convective and stratiform precipitation is the presence of a melting layer in the stratified precipitation whose thickness has been measured by radars from 0.3 to 2.5 km below the zero isotherm height. The radiative transfer modeling of the melting layer strongly depends on the composition and characteristics of melted particles which vary with height. These properties are not well known, however, for radar backscatter applications mainly ice inclusions in a water matrix are assumed. Other aspects are particle density as a function of size and particle size distributions.

Simulations of microwave emission from stratiform clouds show a considerable effect of the above parameters which have to be carefully chosen once these simulations are to be employed for hydrometeor retrieval algorithms based on both emission and backscatter measurements. Ambiguities related to the uncertain state of melting layer microphysics reflect into a large non-uniqueness of the inverse solution, given in terms of hydrometeor profiles. These effects will be demonstrated on the basis of cloud model simulations providing consistent hydrometeor fields including diverse particle types and explicit treatment of particle spectra and density.

An opportunity to test models against high-resolution aircraft measurements has been represented by the Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (TOGA-COARE), one of the most recent and intensive campaigns in the framework of the Tropical Rainfall Measuring Mission (TRMM) preparatory projects It was carried out over the tropical south Pacific Ocean during November-December, 1992 and January-February, 1993. During TOGA-COARE data has been collected from the Advanced Microwave Precipitation Radiometer (AMPR), having four channel between 10 GHz and 85 GHz, has flown aboard the ER-2 NASA aircraft, together with the Millimeter Wave Imaging Radiometer (MIR), having six channels between 89 GHz and 220 GHz. Case studies of stratiform cloud overflights are used to demonstrate the presence of melting layer effects on upwelling radiance emission and radar backscatter. Radiative transfer simulations are used based on the above cloud model data to improve inversion-type retrieval algorithms applied to aircraft data. Finally, the possible impact on retrieval algorithms for satellite data is analyzed.

Cloud parameter retrieval from spaceborne microwave radiometry : a comparison of cloud signature simulations to SSM/I historical data over the Mediterranean area

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Over the past decades, many studies have been made to delineate the modeling frameworks for interpreting microwave radiometric data from satellite over precipitating clouds. The aim is the retrieval of relevant cloud parameters, especially hydrometeors in different phases (iced and liquid) and surface rainfall rate (T.T. Wilheit et al., *Rem. Sens. Review*, 11, 1994). The availability of a reliable database of the profiles of cloud parameters is of major importance in this respect. However, the scarcity of experimental data concerning cloud systems and the surface underneath make it necessary to tackle the problem through the use of cloud models of different kinds.

In previous works, we have used the output of a microphysical model (UW-NMS) which referred to a particular precipitating event (N. Pierdicca et al., *IEEE Geosc. Rem. Sens.*, 34, 1996). Subsequently, we have extended such a data base to include cloud genera which were scarcely represented, such as stratus and stratocumulus (d'Auria et al., *Radio Science*, 1998). A radiative transfer model (RTM) has been used to obtain the corresponding T_B values at the four frequency channels of SSM/I (19.35, 22.235, 37.0, 85.5 GHz). The simulations have been made assuming meteorological profiles from the climatology of the considered region and including diverse backgrounds (sea and ground). A Maximum a Posteriori Probability criterion has been further developed to classify the SSM/I cloud covered pixels according to the Cloud Atlas genera and to estimate the coarse profile of different hydrometer contents.

In this paper, we will face the problem of assessing the accuracy of the proposed inversion scheme. From simulated data only we have found a cloud classification accuracy of 81% over sea and 75% over land, while the rain rate accuracy is in the order of 5 mm/h. Moreover, we have planned a validation activity using SSM/I data compared to in situ measurements collected by meteorological networks in Italy. Here we report only about the potential of the simulated data bases to represent the signature of the precipitating events detected by the radiometer. To this aim we have processed a large amount of SSM/I data over the Mediterranean area spanning the time period from 1992 to 1995 (provided on request by NASA-DAAC). We have selected the T_B measurements in geographical locations where the presence of rain was ascertained from the in situ network and the surface contribution in the radiative transfer model could be accounted properly. The presence of such measured signatures in the simulated data base for that location is a necessary condition; it is not sufficient since the location may not be exhaustive in terms of precipitating events. On the other hand, we have selected all pixels that respond to a criteria for detecting precipitation. The presence of signatures outside the data base give an indication of how exhaustively the data base cover the possible cloud conditions in the specified area of interest, but it also indicates the goodness in the simulation of surface effects. Some preliminary results on the validation of the surface rain rate estimation from satellite are also given.

Neural Networks for the Retrieval of Atmospheric Profiles : Data Feature Extraction and Dimensionality Reduction

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A new neural network algorithm for the inversion of radiometric data to retrieve atmospheric profiles of temperature and vapour has been studied.

The potentiality of the neural networks has been exploited not only for inversion purposes but also for data feature extraction and dimensionality reduction. The latter issues have been investigated by using a multilayer auto-associative neural network which maps each input vector onto itself.

Error minimisation in this case represents a form of unsupervised training, since no independent target data is provided. Such a neural network effectively performs a non-linear component analysis and it has the advantage of not being limited to linear transformations, although it contains standard principal component analysis as a special case. In its complete form, the algorithm uses a neural network topology consisting of 3 stages: the input stage performs the dimensionality reduction of the input, the middle stage performs the mapping between the dimension reduced input-output vectors, the third stage brings the output vector back to the desired actual dimension.

The global inversion problem considers atmospheric profiles of temperature and water vapour. They belong to sets of radiosonde profiles over various location in Italy and comprise different meteorological conditions including the presence of fog and clouds. The brightness temperature corresponding to each atmospheric profile has been computed by using Liebe's millimeter-wave propagation model. To simulate noise in the radiometric channels, random fluctuations with different values of standard deviation have been added to the brightness temperatures data. Ground measurements of temperature, relative humidity and pressure, and the height of the base of the cloud, if present, have also been considered in the input vector.

The performances of the algorithm have been compared to those obtained by means of a statistical linear regression algorithm and of the NOF-NN (Natural Orthogonal Functions - Neural Network) algorithm.

Microwave and Infrared Measurements Used to Validate Water Wapor Retriveals from Sunphotometer Data

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A sun photometer (18 channels between 300 and 1024 nm) has been used for sensing the columnar content of atmospheric water vapor via solar transmission measurements in the 719, 817 and 946 nm water vapor absorption bands. The unknown quantity is the band-weighted transmission function determined by the particular spectral absorption of water vapor and the spectral features of solar irradiance and system response. The transmission function is approximated by a two-parameter model.

The unknowns can be determined by using model predictions from the atmospheric transmittance code MODTRAN 3.5, considering appropriate standard atmospheres. Independent validation of the 946 nm channel using simultaneous and collocated columnar water vapor retrievals of a 20/30 GHz microwave radiometer has shown an overestimation of the columnar water vapor by the sunphotometer [1]. Here we applied the same empirical approach to determine the two parameters. Particular emphasis is given to the capability to derive water vapor using the 719 and 817 nm absorption bands in addition to the well-known behavior of the retrieval from the 946 nm channel. During 1996 continuous measurements in Bern (560 m a.s.l.) of both instruments reveal a good correspondence on the basis of the microwave radiometer calibration. This result is confirmed by comparisons between the two instruments and the data from radiosondes at a distance of 40 km. In 1997 the performance of our sun photometer to determine water vapor is tested at the high alpine site Jungfraujoch (3580 m a.s.l.) with independent measurements of a Fourier transform spectrometer (FTS).

These comparisons shall be discussed in order to show how the sun photometer is capable for accurately measuring columnar water vapor in daytime provided there are periods with direct sunlight.

Reference

[1] Schmid B., K. J. Thome, P. Demoulin, R. Peter, C. Mätzler, and J. Sekler, Comparison of modeled and empirical approaches for retrieving columnar water vapor from solar transmittance measurements in the 0.94-mm region, J. Geophys. Res., Vol. 101, 9345-9358, 1997.

Water Vapor Isotope H_2O^{18} and Ozone in the Middle Atmosphere Derived from Millimeter-Wave Radiometry of Transition Lines Near 203 GHz

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Water vapor is a useful tracer for investigations of transport processes in the middle atmosphere like meridional transport and stratosphere-troposphere exchange. H_2O is also important for chemical processes since it is the major component of the hydrogen budget in the middle atmosphere. Additionally, H_2O is a source gas for the highly reactive OH radical. The ratio of H_2O to its isotope H_2O^{18} in the stratosphere is different with respect to the standard mean ocean water value. Since the sources for tropospheric and stratospheric water vapor are not the same, differences in the isotope ratio profile may be used to track the origin of the observed airmasses.

For several years a ground-based millimeter-wave radiometer observing the pressure broadened 204 GHz chlorine monoxide transition line has been operated at the International Scientific Station Jungfraujoch (46.5°N, 7.5°E,alt. 3580 m) in the Swiss Alps. The instrument participates in the Network for the Detection of Stratospheric Change (NDSC). For this work, the radiometer was tuned to 203.41 GHz for measuring the transition line of the water vapor isotope H_2O^{18}.

A cryogenically cooled Schottky diode mixer is used to measure the very weak H_2O^{18} line in a beam switching mode. The frontend of the instrument is equipped with a Martin-Puplett interferometer as single sideband filter. A diplexer feeds the local oscillator signal quasi-optically to the mixer. The backend consists of an acousto-optical spectrometer (AOS) with 1725 channels covering a bandwidth of 1 GHz. The single sideband receiver noise temperature of our system is 2200 K.

We present measurements of H_2O^{18} made in autumn of 1997 during days with extremely low tropospheric opacity. For the data analysis we use difference spectra integrated over approximately one day to achieve a sufficient signal to noise ratio. Volume mixing ratio profiles in an altitude range of 20 to 50 km with a resolution of 15 km are retrieved using the Optimal Estimation method. Comparing H_2O^{18} to available correlative H_2O measurements we can estimate the ratio of H_2O^{18} to H_2O in the middle atmosphere. Since the ozone transition line at 204.45 GHz which is rather strong compared to the H_2O^{18} line, is also located within the bandwidth of our spectrometer, we retrieve vertical ozone profiles in addition to the H_2O^{18} profiles.

Measurements of ClO, HCl and Ozone in the Arctic Vortex with an Airborne Submm Radiometer

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To understand the process of chlorine activation, which is responsible for the large depletion of polar ozone during winter and spring, it is essential to study the horizontal and vertical distribution of ozone (O_3), reactive chlorine monoxide (ClO), and the long-lived chlorine reservoir hydrogen chloride (HCl) in the lower stratosphere. We measured the emission from rotational transitions of these species in the submillimeter-wave range with the Airborne Millimeter- and Submillimeter-wave Observing System (AMSOS) during winter 96/97 and 97/98.

The submillimeter-wave configuration of AMSOS is a heterodyne receiver with a quasi-optical coupling scheme for both signal and local oscillator radiation. A cooled Schottky diode mixer detects the weak atmospheric signals in two sidebands centered at 625 GHz and 650 GHz. The image sideband is suppressed with a Martin-Puplett interferometer. A rotating mirror switches the antenna beam periodically between a hot-cold calibration unit and the atmospheric path at 16° elevation. The spectra are analyzed with a high resolution chirp-transform spectrometer (CTS) and a broadband acousto-optical spectrometer (AOS) with an overall bandwidth of 1 GHz. From the pressure broadened emission lines the volume mixing ratio (vmr) profiles of ClO and HCl can be retrieved simultaneously with the O_3 profiles, using a least squares inversion algorithm. The radiometer operates aboard a Learjet of the Swiss Airforce at an altitude between 9-13 km to reduce the absorption caused by tropospheric water vapor.

During our campaign in winter 96/97 we performed several flights from Switzerland to Spitzbergen, where we observed high ClO values within the polar vortex. In winter 97/98 more flights are planned with an improved instrumental setup. We present the results of these measurements and their comparison to atmospheric model calculations as well as independent measurements from other instruments.

How Microwave Measurements of Ozone Can Complement Balloon-Borne Radiosoundings

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Atmospheric ozone profiles obtained by balloon-borne radiosoundings have to be scaled to coinciding total ozone measurements, as performed by Dobson- or Brewer-spectrophotometers in order to ensure the consistency between the two methods. Since the radiosonde measurements are limited in height by the balloon-burst altitude (typ. 30 km), an extrapolation above this level is needed to compute the total column ozone from the soundings. The standard method consists of assuming a constant ozone mixing ratio above the balloon-burst We investigated the influence of the constant volume mixing ratio extrapolation on the subsequent scaling of the radiosonde profiles, and show to what extent microwave data could be used in order to replace the total ozone measurements for the scaling of the radiosonde profiles. We compared about 350 ozone profiles, measured between November 1994 and June 1997 by balloon-borne Brewer-Mast ozonesondes at the Swiss Aerological Station in Payerne (46.5 N/6.6 S), with coincident measurements with the GROund-based Millimeter-wave Ozone Spectrometer GROMOS at the University of Bern (40 km NE from Payerne).

The results of this comparison will be shown; in particular, the dependence of the scaling of the radiosonde profiles on the limit altitude above which the residual ozone is calculated will be discussed. Different possibilities of using microwave profiles instead of total ozone measurement to perform the scaling will be presented.

Radiative Transfer in the Atmosphere-Ocean System : the Finite Element Method

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The Finite Element Method (FEM), which has already been successfully used to solve the Radiative Transfer Equation (RTE) for a multi-layered atmosphere, has been extended in order to consider a nonuniformly refractive medium, i.e. the ocean-atmosphere system.

The medium can be divided in a suitable number of plane-parallel layers to account for the vertical distribution profile of the atmospheric and oceanic components.

At the interface between the two media with different refractive index properties (namely the atmosphere and the water) the refraction and reflection of the radiation has been modeled through the implementation of the Snell and Fresnel laws. The Fresnel law modifies the form of the RTE and, consequently, also the expression of the solution is modified and it becomes media dependent. Moreover a new type of boundary condition at the interface between air and water must be considered.

The model can account for a bi-directional reflectivity of the underlying surface. The solution obtained is piecewise linear. In order to make it smoother and in such a way closer in analytical properties to an exact solution, the obtained solution is also analytically interpolated.

The final output is the diffuse radiance, resolved in its azimuthal and zenithal dependence, at any optical thickness.

The model ensures the total flux conservation independently on the number of grid points and on the shape of the phase function. It is therefore particularly suitable to deal with marine aerosol atmosphere and oceanic components, whose phase functions are characterized by a pronounced forward peak. The resulting code seems to be very promising for practical applications.

The model has been validated by comparing the results with a backward 3-D Monte Carlo.

Session L12
Monday, July 13, PM 13:40-16:20
Room R01
Sensors : Radar and Radiometer I

Chairs : B. Blume, R. Smith

Radarclinometry

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Radarclinometry is a way to obtain an information of relief with a single Radar image. It makes use explicitly of the dependency between the orientation of a parcel of ground with respect to the sensor direction and the received energy. It provides the altitude of any point by slope integration. Since the seminal work of Widley, a few papers have been published on this topic, either to provide experimental results or technical solutions. In this paper both aspects will be addressed.

Radaclinometry may be seen as a special case of shape from shading a technique which received a large attention from the computer vision community. Its main differences come from the facts that:

i) the emitter and the receiver are in the same direction,
ii) microwave imagery is much more sensitive to the geometrical aspects of the target than the optical range imagery.

Based on these remarks it may be expected that efficient methods could be derived in radarclinometry, although only poor results exist in optics. Unfortunately microwave imaging is suffering from speckle noise which will certainly introduce a major limit to radarclinometric performances.

The solution that we propose is intended to provide a qualitative information on the relief of large and rather homogeneous areas which could hardly be cartographied by other techniques.

We experimented it on the Amazonian forest of the French Guyana. The original method that we propose is based on a two step processing :

1. by use of some simplifications which will be discussed in this paper, we first obtain a rough altitude map by a linear estimation of the local slope as the solution of the radar equation inversion ;

2. by use of a contextual relaxation technique based on a Markov random field, we itaratively improve this altitude map by constraining the relief to verify a local regularity assumption.. If information on the altitude of some points of the scene exists, it may be incorporated to the process and therefore it may contribute to the final DEM quality.

Several problems remain at this point, which are related to the knowledge of some properties of the scene to be analysed. They are linked to the determination of some parameters of the model. They will be discussed in the paper.

At this stage we obtain a dense altitude map on a grid at a planar resolution close to the Radar resolution and with an excellent qualitative reproduction of the landscape profile. Quantitative altitude information remains coarse when compared with conventional DEMs, but it may be sufficient for many practical applications. This point will be discussed.

We have drawn the experimental part along two different axes: by simulation, and on real images. Simulations not only allow to optimize the algorithms, but also provide quantitative information about the performances of the method. Experimentations on real images have been directed with different objectives: we conducted extensive DEM evaluations on yet un-cartographied areas of Guyana (several hundredth of square kilometers), we compared the different sensors from ERS, JERS and Radarsat on the same areas, and we compared the role of the angle of observation with different acquisitions of Radarsat.

Naval Special Wareface PMMW Data Collection Results

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Coastal Systems Station under the sponsorship of the Marine Corps Amphibious Warfare Technology Directorate are exploring the use of a Passive Millimeter Wave (PMMW) sensor for stand off airborne mine detection. In the development of any new technology application, there exist a critical need to develop a balanced modeling and measurement capability. Both will complement one another. Nichols Research has established a physics-based image modeling capability for Passive Millimeter Wave (PMMW) systems. This modeling capability has been used to estimate the performance of a PMMW mine detection system. But, in order to accurately predict the performance of a PMMW imaging system, the background clutter characteristics must be characterized and the modeling results verified against measured data. In fact, in the case of a well designed sensor, the background clutter will define the systems overall performance making accurate knowledge of the clutter statistical variations critical. However currently, there is a lack of high resolution PMMW imagery of backgrounds, due to a lack of data collection instrumentation.

This paper will present the results from a preliminary PMMW data collection to provide data for the assessment of a PMMW mine detection system. The data collection results will characterize both surface and buried mine detection capabilities under a variety of conditions. It is a well established fact that no single sensor will be capable of solving the mine detection problem. Instead, a suite of complementary sensors is required. There is however a lack of an extensive data set of sensor modalities collected in a single sample area. Therefore as a secondary objective of this data collection several sensor modaliies will be used to simultaneously collect mine and minefield data. These results will also be presented.

Key Words : passive millimeter wave, sensor, data collection, modeling

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Biography

Mr. Bradley T. Blume, currently manages the Panama City, Florida technical office. Mr. Blume holds a B.S. (1991), and a M.S. in Electrical Engineering (1993) from Auburn University. Mr. Blume has supported Eglin AFB's Smart Tactical Autonomous Guidence (STAG) program in the feasability analysis of a PMMW sensor for the terminal guidence of bombs and cruise missiles. Mr. Blume has managed several programs in support of the Naval Surface Warfare Center Dalgrahen Division at Coastal Systems Station. In support of the Coastal Beach Reconaissance and Analysis (COBRA) program Mr. Blume has developed phyics-based minefield image synthesis capabilities, and mine detection algorithms. Mr. Blume has also overseen the validation of the minefield imaging synthesis tool through performance comparisons with measured imagery. In addition Mr. Blume provides support to other sensor system analysis and developments.

Passive Millimeter Wave Imaging Device for Naval Special Warfare

F. Downs, Code A31

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Naval Coastal Systems Station (CSS) has teamed with Eglin Air Force Base to develop a passive imaging antenna coupled microbolometer. The device has many applications such as, imaging through adverse weather, counter terrorism, detection of improvised explosive devices inside nonmetallic containers and detection of weapons concealed under clothing. The device used for the Phase I testing is a single element line scan sensor with the ability to image at 35, 60 and 95 Ghz. Phase I will be to determine the limits of passive millimeter wave (PMMW). Results and images of the Phase I test will be presented along with an overview of the sensor development and future plans for exploitation of antenna coupled microbolometer technology.

3D Migration/Array Processing Using GPR Data

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In seismic applications, migration often clarifies reflection patterns from complex geologic structures which generate relatively high signal to noise data. With certain notable exceptions, there is typically an extensive 2D tendency to the deep and large scale seismic reflection boundaries. In the smaller scale near-surface environment surveyed by GPR, it is common to have significant 3D tendencies in both the noise/clutter environment, and the target characteristics. From this perspective, there may be many more circumstances in GPR surveys where the added time and costs of data collection and 3D migration analysis are offset by the increased target resolution and noise suppression capabilities.

We have written and tested a hybrid Kirchoff-like 3D migration algorithm for GPR data to demonstrate target detection and noise suppression improvements compared to conventional 2D time domain migration methods. The method is formulated for coincident transmitter and receiver and includes migration formalisms for planar reflectors, 2D cylindrical bodies, and point diffractors. We also include the radiation pattern effects for an interfacial point source dipole.

We test the algorithm on synthetic data generated from plane reflectors, cylinders, and point diffractors situated in low signal to noise host materials. Using the synthetic data, quantitative performance analysis are done. We also discuss 3D migration results from GPR data collected at a test facility at Camp Borden Ontario, and data collected on the Gulkana Glacier, AK. In addition, we discuss preliminary results from adaptive high resolution time domain spatial filtering using synthetic and field data.

Point-Matching Technique for Computation of Magnetic Field Perturbation by Finite Length Crack in High Sensitivity ACFM Technique

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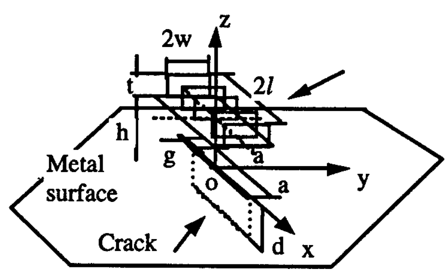
The alternating current field measurement (ACFM) is an electromagnetic technique for detecting and sizing surface cracks in metals [1]. In this technique a thin-skin eddy current is induced in the metal which in turn, produces a magnetic field above the metal surface. A defect in the metal surface causes a perturbation in this field which can be detected by a magnetic probe. In the high sensitivity ACFM, the probe is a thin linear coil and the inducer is a rectangular coil or a rhombic wire loop, fixed together in a special orientation.

In the model-based inversion of ACFM crack signals, a mathematical modelling of the interaction of the inducer field and crack is required. Finite element and finite difference techniques can be used for this purpose, but they are usually slow when the current depth is very small in the conductor medium. This is because of the requirement of very fine mesh for approximating the current distribution.

In a previous paper, we have presented a mathematical modelling of the interaction between the field of an arbitrary shaped inducer and a long uniform crack [2]. In this paper, the development of the extension of the solution to problems of cracks with finite length which can be approximated by a rectangular boundary, is presented. In this solution the point-matching technique is employed to satisfy the boundary condition along the crack line. Although there is no restriction on the shape of the inducer, in the example to be presented, the incident field is produced by a current carrying rectangular coil, Fig.1. The modelling can deal with both open and closed cracks. It uses a well-known boundary condition at the metal-air interface, derived by assuming a thin-skin field inside the metal and by conserving the magnetic flux at the crack mouth. The boundary condition is a second-order differential equation in terms of the incident and scattered scalar magnetic potential. Efficient solution of the problem is achieved by using a two-dimensional Fourier transform, together with the Fourier domain scalar magnetic potentials. Based on the solution, we have developed a computer program which can predict the crack signal. The accuracy of the method is verified by comparing the predicted and the experimental results. An example result is shown in Fig.2.

Fig.1 A rectangular coil (inducer) located symmetrically above a rectangular crack.



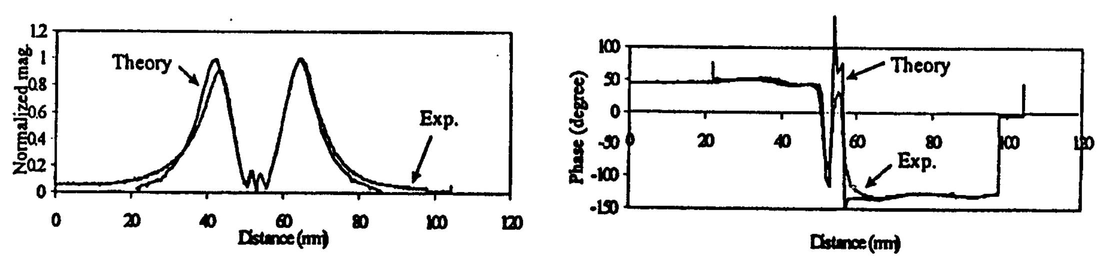


Fig.2 Theory and measurement for the magnitude and phase of Hy along a line in front of a rectangular coil symmetrically located above a crack, Fig.1, in a mild steel plate.

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Recent Advances in High Sensitivity ac Field Measurement for Electromagnetic Non-Destructive Evaluation

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The alternating current field measurement (ACFM) technique is evolved from the AC potential drop method, mainly for the detection and sizing of surface cracks in metals. In the original ACFM [1], [2], a uniform thin-skin eddy current is made incident upon the crack, and a vertical or horizontal magnetic probe is used to detect perturbations in the magnetic field above the metal surface, Fig.1.a. Unfortunately, in the uniform field ACFM, the field is not affected by the depth of a uniform crack (ie: long crack in practice) and any signal detected, is mainly due to the crack gape.

In order to overcome the problem of sensitivity to depth for long cracks, we showed previously that the use of a finite size inducer is necessary [3]. Near a crack, the field of such an inducer is a function of the crack depth. A suitable inducer is a small rectangular coil, and the probe can be a small wire wound coil located below the inducer. The probe can be attached to the inducer in various positions and with different orientations. For example, it can be attached to the inducer with its axis parallel to the axis of the inducer, Fig.1.b. In this position, it behaves as an absolute probe. It is well-known that absolute probes use up the detector dynamic range in an inefficient way. This problem can be removed using a differential probe or a bridge system, but the associated electronic circuits add to the complexity of the detector.

Another position of the probe is in the front of the inducer, Fig.1.c. It was found that when the probe is a linear coil with its axis normal to the inducer axis, the sensitivity increases significantly. This high sensitivity ac field measurement (ACFM) is a powerful alternative to the conventional eddy current technique. It does not require an electronic bridge or a differential probe.

In this paper, initially a review of the ACFM technique in crack detection and sizing is given. Then the principles behind the high sensitivity ACFM are addressed. Recent advances in this technique, including the development of flat inducers, accurate modelling of field-flaw interaction, and techniques for crack signal inversion, are reported. The applications of the technique in detection of cracks using high lift-off probes, shallow cracks, cracks in welded areas and heat affected zones, are highlighted. Also, a linear array system based on the high sensitivity ACFM for detection of defects in large metal surfaces, is discussed.

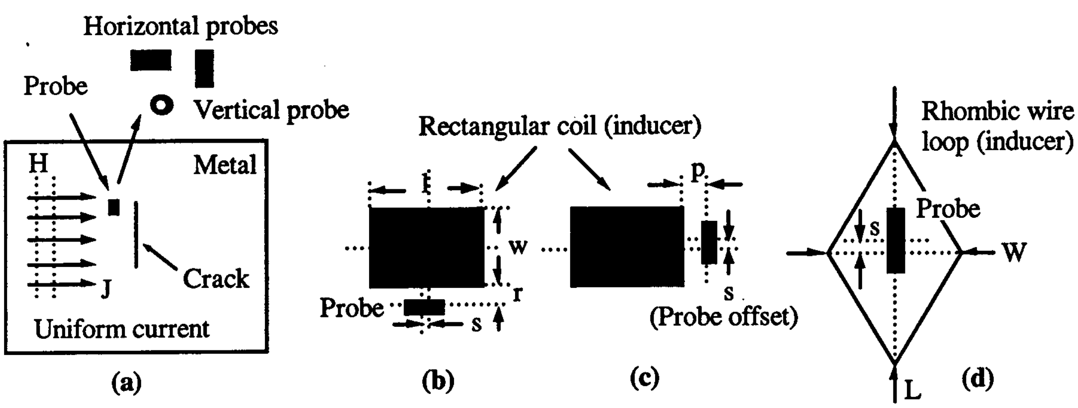

Fig. 1: (a) Uniform field ACFM,
(b) inducer and probe combination which makes ACFM sensitive to the depth of long cracks,
(c) and (d) probe and inducer combinations for high sensitivity ACFM.

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A Fast Multilevel Algorithm for Radar Imaging

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Radar imaging has gained wide popularity in a variety of civilian and military applications. The Synthetic Aperture Radar (SAR) images are obtained by processing radar scattering data collected over a range of angles and frequencies. While most processing techniques are formulated as integral transforms, high computational complexity effectively precludes straightforward numerical evaluation of the integrals involved. Conventionally, an integral transform is brought to a multidimensional Fourier transform form whose discrete numerical implementation is effected by a Fast Fourier Transform (FFT) based algorithm. However, in some instances the reduction to a Fourier form can be achieved only at a price of far reaching approximations, which adversely affect the accuracy of the resulting images.

In this paper we propose an algorithm which is applicable to imaging situations that are not amenable to the FFT based methods while approaching their computational complexity. The algorithm is based on the observation that we can, first, form a series of low resolution smoothed images using subsets of the data and, later, aggregate these images into a high resolution final image. Thanks to their bandlimited nature, smoothed images can be evaluated at a small number of points, thus reducing the computational cost. The aggregation step involves computationally inexpensive interpolation of the low resolution images to the required resolution with subsequent multiplication by exponential factors. The multilevel algorithm is formed by repeating the aggregation step, while gradually proceeding to higher and higher resolutions. The overall structure of the algorithm resembles that of the FFT and it is closely related to the methods recently introduced in computational electromagnetics and image processing.

In this paper, the algorithm is formulated, specifically, for the near-field imaging. Numerical examples demonstrating the accuracy and efficiency of the method are presented.

Session L01
Monday, July 13, PM 16:20-18:20
Room R01
Antenna Arrays in Mobile Communications

Organiser : L. Godara
Chairs : L. Godara, J. Saillard

Phased Array Antennas for Mobile Communications

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Phased array antennas have been considered the most favorite candidate, and been developed for mobile communications, especially for mobile satellite communications. It has many advantages in communications such as light weight, simple configuration and high speed satellite tracking capability. However, it has also such disadvantages as beam scanning errors and noise increase in case of signal transmission. This paper presents activities in Japan on research and development of phase array antennas, which covers antennas for satellites, aircraft, land mobiles, and hand carrying terminals.

Ambiguities in Antenna Array for Mobile Communications

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Exploitation of spatial dimension can improve capacity, coverage and quality in wireless communication. A space time receive modem operates simultaneously on all the antennas, processing signal samples both in space and time. This extra dimension enables interference cancellation in a way that is not possible with single antenna modems. The desired signal and cochanel interference arrive at the antenna array with different spatial signature, allowing the modem to exploit this spatial diversity. Linear dependance amongst the array antenna manifold (steering vectors) leads to a failure of the subspace based method (for example MUSIC) to correctly identify the source location. These manifold ambiguities will provide parasite peaks in the spatial spectrum. The aim of this paper is to study the presence of manifold ambiguities (grating type ambiguities) for an array of given geometry. For arbitrary linear arrays, we provide an insightful geometrical interpretation of manifold ambiguities from rank one to rank n ambiguities. We establish geometrical properties of manifold ambiguous arrays and we deduce a sufficient condition for the presence of manifold ambiguities. Some interesting results are derived for sparse linear arrays. Rank one and two manifold ambiguities are studied for an arbitrary planar array. We propose a general framework for the analysis and so we obtain a generalisation of results given in recent publications.

Space-Time Diversity Receivers for DS-CDMA Systems

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This paper proposes a study of a space-time diversity receiver which realizes a 2D-Rake receiver for DS-CDMA systems. This type of receivers can achieve a fading reduction by the coherent sum of the multipath received on different antennas [1]. Generally the diversity branches are assumed independant This assumption supposes that the antennas are enough remote or that the angular spread of the received signals is large.

Here we are interested by small size antenna arrays compatible with the dimensions of a terminal. We assume that the 2D-Rake receiver achieves the coherent summation of the instantaneous signal to noise ratios received on the antennas. For example, this can be obtained using the algorithms proposed in [2] and [3]. The fading reduction can be characterized by a coefficient of variation [4]. The expression of this coefficient is given here in the case of non-independant branches for space and space-time diversity. Then, different antenna arrays are compared in function of the angular and time spread distributions of the channels.

A trade-off between time and space diversity can be deduced from these results for different signal configurations.

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Adaptive Unequally Spaced Phased Arrays

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The objective of the presentation is to illustrate how to process data in the presence of strong jammer and clutter utilizing non-uniformly spaced phased arrays. Typically, one can use a circular, hexagonal or a cross for more efficient utilization of the aperture. The second possibility is that one may be dealing with a non planar phased array not by choice but due to vibration of the aircraft structure or the sonobuoys bobbing up and down in the ocean or a towed phased array. In these situations it is desirable to perform adaptive processing to enhance the signal in the presence of strong clutter and jammers. Conventionally, the analysis procedures primarily deal with uniformly spaced linear phased arrays and practically nothing is available in the published literature on how to perform adaptive processing utilizing non-planar and non-uniformly spaced arrays. The talk will outline a direct data domain approach for the extraction of the desired signal adaptively in the presence of strong signal and clutter.

Since it is a least squares approach the adaptive procedure provides the best estimate. The adaptive process is carried out utilizing the conjugate gradient method and hence the it is possible to implement the algorithm on a signal processing chip to adaptively enhance signals received by a non-uniformly spaced array in the presence of strong jammer, clutter and thermal noise.

In contrast to a covariance based approach the direct data domain approach is fast and accurate. In addition, for a covariance based statistical methods which is the current state of the art, it is difficult if not impossible to handle signals from non-uniform arrays as it is difficult to form an estiamte of a uniformly sampled covariance matrix from an unequally spaced data sets.
Results will be presented utilizing a circular, hexagonal and a sinusoidally modulated array.

Circular Antenna Array Fed by a Seven-Port 'Ring-Star' Divider

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Future mobile communication services, in many urban or indoor scenarios, will require frequencies close to the millimeter-wave range in order to accomodate multi-megabits/s rates. Multipath propagation problems and reduced reception effective area will require directive antennas on the terminals. We therefore propose here a new approach, based on electronically controlled circular antenna arrays to provide this directivity. Such antennas can be useful in WLANs operating e.g. at 5 or 17 Ghz (HIPERLAN).

To achieve 360° azimuthal coverage, we chose to develop circular arrays of monopoles [1]. Each monopole is connected to a series impedance (two different values possible) providing directivity by rotational symmetry breaking. Design simplicity intended for potential low-cost applications has led us to privilege a single feeding-point. In the present work, the structure consists of a circular array of six (l/4) monopoles perpendicularly connected to a microstrip circuit, through vias in the common ground plane. In a fully operational version, this connection will be dynamic (active switches). Presently we intend to demonstrate the principle of antenna operation through a fixed reactive impedance configuration.

Monopoles excitation is carried out by a seven-port 'ring-star' divider (including the feeding-line) designed to present adequate voltage phase and magnitude values at the monopoles, in order to achieve satisfactory results in terms of radiation pattern and antenna impedance. This leads to a fully integrated antenna architecture including both the monopole array and the 'ring-star' divider on a supporting single substrate.

Electromagnetical modeling of the array was carried out using the method of moments. Global simulations of the whole antenna and 'ring-star' circuit were performed by circuit and electromagnetic simulators (HP MDS et HP MOMENTUM) at 5 GHz. These results, as well as experimental results will be presented and discussed.

Reference

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An Active Adaptative for HF Communications

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The bandwidth of a typical practical HF communication system is necessary to have 4 to 28 MHz frequency band in order to maintain HF communication over a given path. Effective interference cancellation over a wide bandwidth is a rather sticky problem for adaptive technology. It is the purpose of this paper to present an active adaptative array for high frequency band AM-FM radio communications.

We use an active adaptative array of four active monopole elements which are mounted (center to center) on a square whose side spacings are 9m, the monopole 1.2m long and 3 cm in diameter, and the amplifier circuit is designed so that it is also acts an impedance transformer, matching into the very low impedance of the shirt monopole band compensating for its frequency-dependent reactance [1,2]. We use a narrowband processing method for broadband adaptative communication antenna array -- frequency constraint method on account of the bandwidth of an AM-FM signal of HF communication in practice is generally rather narrow. Because the frequency of the desired arrival signal is contained in the constraint matrix, therefore, when the output power of the system is minimized, the noise and interference trend to be nullified output signal-noise-ratio. With the frequency of the constraint matrix changed, a narrowband signal with various different frequencies may be received [3].

This active adaptative array has simple structure, considerable convenient to install and small computation complexity. The experiment results demonstrated that it may provide a satisfying interference suppression in the HF band communication. We are now considering the development of a more sophisticated array, with more elements in a variety of layouts.

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Session M01
Monday, July 13, PM 13:40-17:00
Room R03
Material Measurements I
Workshop on Complex Media and Measurement Techniques
Organiser : A. Mamouni
Chairs : T. Larsi, J. W. Odendaal

Gas Absorption Measurement in the Millimeter/ Submillimeter Band by Vector Signal Detection

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In order to developp an in-situ gas sensor effective to industrial gas processes, especially leading to the clean air preservation, authors have investigated a spectrometric instrumentation by vector signal detection. The method of vector signal detection in the gas absorption measurement, where a gas is filled in the Fabry-Perot resonator, will provide capabilities of fine frequency resolution and non-absorption signal identification which are vital for the sensitive response to the change of the gas temperature and density. It also embodies an apparatus of small size and high operability.

The current setup is composed of a vector network analyzer with the highest frequency of 350 GHz, a Fabry-Perot resonator and a gas container. The resonator has the highest Q at 92 GHz, and the resonant frequency can be tuned over the range of 50-150 GHz. The gas container has a cylindrical shape, configured to the internal structure of the resonator cavity. The material of the cylindrical wall is polyvinyl chrolide, and the window at the both ends is made of polyvinyliden thin film for the first version.

As the first step, the oxygen gas absorption in the 60 GHz band for1-atmospheric pressure has been measured and the observed profile is in good agreement with the predicted.

At the symposium, the design concept, apparatus description, and the current and progressive results will be presented.

Measuring Density of Snow Particles and its Effect to Radio Wave Attenuation

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It is important to measure the density of falling snow particles as a help with the determination of a dielectric factor in analyzing radio attenuation during snowfalls.

To measure a mean density of falling snow particles per minute for a long period of time automatically, their total volume was observed using the image processing technique. A side view of snow particles falling into a tower was taken by a CCD TV camera and their images were input into an image processor controlled by a personal computer. The diameter, fall velocity particles and number concentration of snow were calculated from their images. The total volume of falling snow particles which pass through a unit space per second was calculated by these data. Simultaneously, the total weight of snow particles per unit volume that have fallen to the ground was measured directly by an electronic balance. The average density was calculated by dividing this weight by the total volume obtained from
their diameters and fall velocities.

At the same time with this observation, the Doppler velocity spectrum of scatters from snow particles was measured using a small X-band bistatic Doppler radar developed as a Precipitaion Occurrence Sensor System (POSS).

X-band wave attenuation due to size distribution, number concentration, fall velocity and density of snow particles have been observed.

Measurement of Material Constants in Near Zone of Electromagnetic Horn

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Free space measurement methods for microwave properties of materials is a problem of the current interest. Methods of this kind are unavoidable in investigation of inhomogeneous materials as well as in non-destructive material testing.

An attractive approach involves performing the measurement with a sheet sample located immediately against the aperture of an electromagnetic horn. This approach provides wide possibilities for incorporating the sample into various multi-slab structures to obtain accurate measurement. Besides, the equipment need not be placed into an anechoic chamber.

Disadvantage of the method is occurrence of additional systematic measurement errors. They are caused by possible multiple reflections between the horn and the sample as well as by non-spherical wave front of the wave radiated by the horn. These two reasons can result in considerable measurement error.

We present an error model takes these errors into account. The approach is based on 3-port model of a horn: two ports correspond to the aperture and the throat of the horn, while an additional port represents energy transfer to higher wave modes that are excited in the horn and are responsible for its resonance properties. Besides, the curvature of the phase front of the wave radiated by the horn is accounted for by description of this wave as an effective plane wave with a complex incidence angle. The value of this angle depends on the wavelength and dimensions of the horn. Introduction of this effective plane wave make it possible to describe interaction of the divergent horn wave with a sheet sample in terms of Fresnel law.

To verify the performance of the model we apply it to the near zone measurement method for permittivity and permeability where these values are extracted from reflectivity of the sample when it is located in free space and is metal-backed. Obtained experimental results are an evidence that implementation of the model diminishes systematic measurement errors so that it becomes negligible small in comparison with random measurement errors.

A Generalized Plane Wave Model for Radiating near Field of Horn Antenna

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The Gaussian beam model is conventional for description of propagation of narrow beams. Unfortunately, this model is not quite adequate for description of a radiating near field of a microwave horn, because in this case the transverse field distribution is more complicated. We present an approach to describe propagation of arbitrary narrow beams.

We introduce a concept of a generalized plane wave (GPW). Accordingly to this concept, one can define complex amplitude, wave number and characteristic impedance in any plane of an electromagnetic field that is perpendicular to certain "propagation direction". In general case, one can separate the field into two GPW "propagating" parts: "incident" and "reflected". The parameters of GPW can be determined after certain transformation of Maxwell's equations that results in two one-dimensional wave equations. This transformation is a generalization of the approach applied in the theory of waveguides.

Introduction of GPW has a practical importance for the case of narrow beams, particularly of the radiating near field of a horn antenna. In this case, the wave number and the characteristic impedance are weakly dependent on the coordinate in the propagation direction. These parameters are complex ever for transmission in vacuum because of the wave divergence. In addition, for the narrow beam there is simplified law of GPW reflection and transmission on a plane boundary of two media. That permits us, in particular, to interpret experimental results for incidence of radiating near field of horn antenna on sheet materials.

Introduction the complex amplitudes in the GPW model gives a possibility to regard the transmission and reflection of the wave radiated by a horn in terms of the circuit theory.

The Use of the Dielectric Properties of Hardening Concrete for Monitoring the Strength Development

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The demand for monitoring systems for hardening concrete increases due to newly developed mix designs. Examples of these advanced mixes are high strength concrete and self levelling concrete. These monitoring systems should preferably be non-destructive, easy to use and robust. In a joint project the TU-Delft, IMAG-DLO and OFFIS are developing a new monitoring system based on the dielectric properties of concrete.

The hardening process of concrete has a dominating effect on the time schedule of the building process. The hardening of concrete is a physical - chemical process in which cement and water react and form a solid material. During hardening the cement grains react with water and will form interparticle contacts which are responsible for the strength.

The dielectric properties of concrete are dominated by the water in the pore system of the hardening cement matrix. Both the amount and distribution of the water in the concrete determine the dielectric properties. Changes of the state of water in the pore system, as they occur with progress of the hardening process, are accompanied by changes in the dielectric properties. Hence changes of the dielectric properties can be used to monitor the progress of the hardening process. The relationship between state of water in the concrete and the progress of the hardening process form the basis for the monitoring system.

The system is based on a chip developed by the IMAG-DLO, which has been used as sensor for other engineering applications. The sensor monitors the dielectric properties and temperature of the concrete. The dielectric measurements are combined with microstructural models, which simulate the reaction of cement with water. Based on this combination reliable predictions of strength development in hardening concrete are possible.

The design of the chip as dielectric strength sensor for concrete will be presented in more detail. Furthermore, the research program, used to underpin the existence of the relationship between dielectric properties and mechanical properties, and some preliminary results, will be presented in this paper.

Characterization of Radar Absorbing Material in the Time-Domain

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The increasing proliferation of sophisticated microwave communication and radar detection systems at international airports have accentuated the problems of unwanted multiple reflections, clutter and mutual interference without adversely affecting system performance and reliability. This will lead to the extensive use of lossy microwave materials at and in the vicinity of airports.

The importance of, and the need for proper characterization techniques for these radar absorbing materials is growing internationally. Previously developed methods measured and contemplated the specular characteristics of a metal plate coated with absorbing materials over an incidence angle ranging from -15^0 to $+15^0$ off specular. The attenuation of the total backscattered electromagnetic field with respect to the incident field over a stipulated frequency range was the sole characteristic measured and published by manufacturing companies.

Some Radar Absorbing Material (RAM) are designed particularly for attenuating creeping wave contributions (e.g. Surface Wave Absorbing Material (SWAM)). Using the existing measurement techniques to evaluate these RAM samples, reflects little or no information to the effect of the surface wave absorption properties of the material. These techniques make use of the transmission and reflection coefficients measured over a frequency range. The result is a superposition of specular and creeping wave performance at best.

In this paper we propose a technique to quantitatively evaluate the RAM properties for specular reflection as well as creeping wave incidence. A test sample is chosen such that the two contributions (specular and creeping wave) are separated in time. This allow the use of time domain techniques to evaluate material, specifically designed for surface wave absorption.

Since the creeping wave is in time delayed from the specular component, it is easy to identify and isolate in the time-domain. Thus the attenuation characteristics of the creeping wave are evaluated more scientifically and with greater accuracy than in the frequency-domain.

Measured results obtained in a Compact Range at the University of Pretoria will be presented for various samples of RAM. The characteristics of the RAM for specular as well as surface wave absorption will be discussed using these measured data.

A Comparison of Measurement Uncertainty in the Measurement of Complex Permittivity and Permeability at Microwave Frequencies Using Transmission Line and Quasi-Optic Systems

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Measurement of the electromagnetic properties (permittivity and permeability) of materials from near DC to the millimetric waveband and beyond is essential for a diverse range of applications. Moreover, it is not sufficient to simply quote a measured value without stating an uncertainty and demonstrating traceability to national or international standards. This is particularly relevant when the measured values are used to engineer products in which accurate specifications and tolerances need to be established.

Indeed, establishing traceability in the measurement of the magnitude and phase of scattering parameters and impedance, the properties from which the intrinsic material properties are derived, is the remit of National Standards laboratories, such as the National Physical Laboratory in the UK. Recent research in these laboratories has extended traceability well into the microwave region enabling more accurate calculation of uncertainties for other related measurements such as those of the microwave permittivity and permeability of materials. This paper presents progress made in the NAMAS Accredited Electromagnetic Measurements Laboratory at DERA in the estimation of uncertainties for such measurements, which are central to its work in the development of composite materials with tailored electromagnetic properties.

It is shown how the measurement uncertainties are influenced by different measurement techniques and sample geometries. In this respect a comparison between results obtained from NAMAS Accredited transmission line measurements and those from other techniques including a free-space quasi-optic system and a broadband dielectric spectrometer will be presented. The materials used in the comparison are polymeric and ceramic in nature, some being purely dielectric and some having magnetic characteristics. The comparison demonstrates the relevance of using different techniques for different types of materials and/or test sample geometries.

New Measurement Technique for the Surface Resistance of Superconducting thin Film

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Measuring cells based on sapphire parallel plate resonator are effectively used in the frequency range (10...30) GHz. These cells have high sensibility and need relatively simple mathematical processing. The parallel plate resonators are excited at H_{011} mode. For such cells the geometrical factor G is 300...600 and depends on cell dimensions, in particular on the diameter of the sapphire rod.

The sapphire rod diameter must be very small at high frequencies for providing condition of single mode regime, there the use of present methodology becomes problematic. Besides the influence of the thin gaps between the rod and endplates on measurement results for elevated frequencies becomes stronger.

Usage of empty metal resonators with H_{011} mode for investigation of superconducting film loss gives the opportunity to conduct the measurements up to 100 GHz. The contribution of the metal walls into resonator Q-factor is the most considerable. The separation of the low loss in the superconducting film from the high loss in the resonator metal walls leads to reduction of measurement accuracy.

Putting into practice of thin sapphire disk resonators (DR) being excited in the azimuthal mode regime gives the opportunity to extend the frequency range of measurements of the superconducting film surface resistance: from 20 up to 150 GHz. The Q value of the resonant structure based on sapphire DR is influenced only by the loss in sapphire and in the investigated film. The sapphire loss at the liquid nitrogen temperature is very low ($\delta \approx 1.10^{-6}$ at 70 GHz), and so the investigated film loss brings main contribution into the Q-factor of the resonant structure. It is possible to place one or two superconducting films at some distance from the resonator. The control of the gap between films and disk allows to change smoothy the value of the geometrical factor G.

The dependence of the geometrical factor G as a function of the gap value has a long enough quasi-linear part with small steepness. In the case of the use of one film the geometrical factor G for various disk thickness is 1000...1200. However the factor G is approximately twice as low if there are two films in the resonant structure. It is possible to employ various design variants of the measuring cell based on the sapphire DR including open and shielded constructions.

In this paper mathematical apparatus has been developed, allowing to calculate the geometrical factor G and resonant frequencies for various measuring cells. The numerical investigations were fulfiled and the data were obtained allowing to make the choice of cell dimensions for a mode type set in a known frequency range. The influence of the gap between the disk and superconducting film on the geometrical factor G and measuring error were calculated.

This investigation show, that the measurement technique for the surface resistance of superconducting films in microwave and millimeter wave range based on sapphire DR with azimuthal modes has obvious advantages with respect to other methods used in SHF technique. Present method ensures high measurement accuracy and the highest sensibility in a wider frequency range.

Measurment of Complex Permittivity and permeability of Dielectric materials using a coaxial Transmission Line with Sensitivity and Errore Analysis

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A simple axperimental method to measure the permittivity and permeability of a unknown solid material will be presented. Material has to be placed in a coaxial line as a part of its propagation media. To measure permittivity and permeability we have to measure the input impedance of the line in two different cases (for example two different loads).

Here instead of two different loads, we use two different positions for the unknown media in the line with, one short circuit load.

So using vector Network-Analyzer one can measure the input impedance in two above cases, and using this results the complex permittivity and pemeability of the material can be computed using some simple mathematical formulations. Finally sensitivity and error Analysis can be done to obtain the influence of each parameter on the error and the sensitivity oft his method to its parameters.

Session A02
Tuesday, July 14, AM 8:40-11:40
Room 300
RCS Models of Large and Complex Structures and Validation

Organiser : E. Kemptner
Chairs : E. Kemptner, U. Jakobus

RCS Computation of Electrically Large Scatterers with the Method of Moments : Parallelization and Hybridization

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The method of moments (MoM) has been used for many years for the analysis of a variety of electromagnetic radiation and scattering problems including RCS computations, mainly in the resonance region or at lower frequencies. With increasing computer power with respect to speed and available memory, its range of application can be extended to electrically large problems.

This paper deals with the parallelization of the MoM and some hybrid extensions for an execution on massively parallel supercomputers such as the CRAY T3E. For the conventional MoM formulation, this allows RCS computations with up to about 50,000 unknowns, corresponding to a surface of approximately 600 square wavelengths (e.g. a cube with a side length of 10 wavelengths). Exploiting symmetry of a scatterer, these limits can even be somewhat higher. Almost no limitation in size exists when using the proposed hybrid extensions, which are also available in parallel.

The various phases of the conventional MoM such as reading and setup of the geometrical data, computation of the matrix elements and the right-hand side of the system of linear equations, solution of the system of linear equations, and near- and far-field computations have been parallelized using message passing interface (MPI) functions. We have concentrated on target machines based on a distributed memory concept (e.g. the CRAY T3E but also a cluster of connected workstations). The MoM matrix and some associated vectors must be kept in memory using a distributed storage scheme such as a block cyclic row distribution. Some optimizations concerning the block size and the numbering scheme of different basis functions for metallic wires and metallic or dielectric surfaces were required in order to ensure a reasonable load balance amongst the different nodes. Library functions from ScaLAPACK are used to solve the system of linear equations leading to the current distribution on the surface of the scatterer. For the following RCS integration, a master/server concept is applied supporting a dynamic load balancing mechanism, which is especially important in heterogeneous computing environments.

But even using the most advanced parallel computers, there will always be a limit for the application of the MoM since CPU-time is proportional to $f^{4..6}$ and the memory requirement grows as f^4 with the frequency f. Therefore, another aspect of this paper is the hybridization of the MoM with high-frequency asymptotic techniques. Current-based methods such as physical optics (PO) with correction terms for edges or wedges and Fock currents are used offering the advantage that a continuous current flow can be modeled on the scatterer's surface across the boundary between MoM- and asymptotic regions. For RCS computations, this current-based hybrid method results in a f^2 dependency concerning memory and CPU-time. Recently, the current-based hybrid method has also been extended by including diffraction theory (UTD). For this technique, the required CPU-time is independent of the frequency.

Validation of RCS Signature Simulations of Ground Targets at Millimeter Wave Frequencies

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Modeling of targets is gaining more and more importance in the development of radar signal processing algorithms for a wide field of applications. Meanwhile a range of electromagnetic scattering models are existing which, based upon CAD data, are able to describe the scattering behaviour of complex targets in dependence of radar frequency and for the geometrical conditions the respective target is illuminated by the radar beam. The applicability of each model is generally determined by the relation between target dimensions and the wavelength of the illuminating radar beam. While most existing simulation tools are more or less validated for classical radar wavelengths, their usefulness for millimeter wave applications is not thoroughly proved. This is especially critical because in this frequency region basic structures as corners, edges and surfaces are never right angled or smooth in relation to the radar wavelength. To tackle this problem, an attempt was started to compare measured RCS characteristics with results from simulations for ground targets of different scale at the two millimeter wave bands of 35 GHz and 94 GHz.

In a first approach target objects with dimensions of fractions of 1 m were measured under full illumination in an anechoic chamber for the full aspect angle range of 360° and different depression angles. The experimental results were compared with those of simulations with different simulation codes. To test larger scale targets, measurements in tower/turntable configuration were conducted in an open air test range again for the full aspect angle range of 360° for one fixed depression angle of about 20°.

The paper describes the experimental set-up and discusses the results of the measurements. A short discussion emphasizes the simulation methods used. The output of the simulations is compared with the experimental results, and the specific features of the millimeter wave region are highlighted.

Radar Cross Section Computation Using RAPPORT and the Method of Equivalent Currents, Results and Validation

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At the Physics and Electronics Laboratory a code has been developed for the analysis of radar signatures of complex objects. This code, "Radar signature Analysis and Prediction by Physical Optics and Ray Tracing" (RAPPORT), is used to predict the Radar Cross Section (RCS) of complicated objects like ships, vehicles and aircraft and to evaluate the effect of RCS reduction measures. The implemented algorithm is based upon a combination of Physical Optics (PO) and Geometrical Optics (GO), as proposed in [1]. Objects have to be described as a collection of flat polygonal plates, because of the adopted method to solve the PO integral [2]. RAPPORT makes use of an efficient backward ray-tracing algorithm to construct the illuminated part of the object, from which the RCS can be computed for any desired number of reflections and frequencies. The accuracy with which this illuminated area is determined can be controlled by a user defined parameter. This feature makes it possible to model very large complex objects like ships and it greatly facilitates the generation of inverse synthetic aperture radar (ISAR) images of the target. Since the first version [3], many new features have been added to the code, for instance improved ISAR capability, multipath computations and the use of non perfectly conducting materials.

In order to overcome the problems with edges that PO based codes encounter, a software tool based on the Method of Equivalent Currents [4] has also been developed at TNO [5]. With this program, called RCS_MEC, the scattering by sharp edges can be computed. To obtain a better representation of the RCS of a target, the scattered fields due to edge diffraction can subsequently be combined with the scattered fields due to reflection, as computed by RAPPORT. Especially when investigating low RCS targets edge diffraction plays an important role. RCS_MEC has the same computational capabilities as RAPPORT, with the exception of the use of dielectric materials. Objects have to be described as a collection of sharp edges with known wedge angles. A pre-processor has been made to extract these edges from the object description of RAPPORT, so both programs use the same object description. The advantage of this is clear, in case of RCS reduction by geometrical adjustments, only one file has to been changed.

During the presentation results will be shown, clarifying the capabilities of RAPPORT and RCS_MEC and the progress that has been made since the first version of the codes. Also validation results will be presented.

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Multiple reflections in greco RCS prediction code

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During the last years, the development of graphical processing techniques for high-frequency monostatic RCS prediction has given rise to GRECO code. Real-time computation is achieved through graphical processing of an image of the target present at the screen of a workstation, using the hardware capabilities of a 3-D graphics accelerator.

GRECO code for monostatic RCS prediction in real time has been extended by considering multiple reflections between surfaces, instead of only double reflections. Multiple reflections are analysed through a very efficient ray-tracing algorithm based on the graphical processing technique.

Multiple reflections between surfaces are analysed by a hybrid GO-PO scheme. The GO reflection at the all surfaces, except for the last reflection, assumes that specular reflection occurs, according to stationary phase principle. The PO reflection at the last surface ensures that the scattered field is obtained when there is no specular reflection to the observer.

For each pixel on the target surface, a reflected ray is traced along the GO specular direction. The impact of the reflected ray with another surface is detected on the screen by following the ray-path and comparing the z coordinates of the ray with that of the surface at the same x,y location.

This scheme is valid for planar surfaces and only approximate for curved surfaces. In the former case, the reflected rays are parallel, which is equivalent to a plane wave incident over the second surface. In the later case, the divergence factor due to the curvature of the surface is approximately accounted in the graphical ray-tracing algorithm: the number of ray-hits on the second surface is inversely proportional to the divergence of the reflected rays.

Validation of Monostatic and Bistatic RCS-Calculations for a Stealth Configuration by Experiments

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In order to minimize the monostatic radar cross section (RCS) stealth configurations usually are designed by modifying the shape and the surface material. In the first step to a DLR stealth configuration the F7 design consisting of perfectly conducting flat plates is investigated. The wavelength used for the configuration is small compared to the dimensions of the airplane. The special shape of stealth configurations is only effective in the monostatic case. Therefore the bistatic case is of special interest for such objects.

The numerical calculations of the RCS are done by two different computer codes, both based on the Physical Optics (PO) approximation. The first one for the monostatic case is SIGMA, which applies Physical Optics approximation (PO) with an extension concerning edge diffraction (Physical Theory of Diffraction, PTD), the second code for the bistatic case is BISTRO. Applying these two codes monostatic and bistatic RCS calculations are carried out and the efficiency of the stealth design is discussed.

In order to verify the theoretical results the experimental setup has been improved substantially in the last years. Build up in an indoor anechoic chamber it allows to measure the monostatic as well as the bistatic RCS of test objects at a frequency of 94 GHz. The movements of the test object and/or the antennas and the data acquisition are fully automated and controlled by software. The manufacturing of scaled models (1:200) of F7 is explained in short.

Finally the theoretical and the experimental results for the monostatic and bistatic case are presented, compared with each other and discussed.

Asymptotic Method in a Multi Domain and Multi Method Approach for Large Targets

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To compute the Radar Cross Section of a modern jet aircraft is a difficult and complex problem. An approach (called the multi-domain and multi method approach) is to split the target in several domains and to use the most suitable numerical method in each domain. To compute a large and complex inlet (which can be represented by one or more domains) of these aircraft, an accurated method is the Finite Element Method (FEM). The Method of Moment (MoM) is very efficient to modelize the scattering in an unbounded domain. How ever for high frequencies, MoM breaks down and asymptotic methods are employed.

In this presentation, we discuss the multi-domain and multi method approach for large targets when the unbounded domain is computed by a P.T.D. approach. The multi domain and multi approach for large targets will be reviewed briefly. (The object is split in N parts, and a scattering matrix for each domain is computed by a well-suited method). The mathematical framework of PTD approach in the multi domain and multi method context will be presented next. The calculus of RCS will be illustrated by cascading the previous obtained scattering matrix. Several numerical exemples will be reported to demonstrate the employed technique.

Some Applications of the DECLIC Time Domain Code for SER Prediction

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Function

The DECLIC code is a tool used to study the electromagnetic behaviour of complex or resonant geometries which can be found for example in missiles. The code uses Finite Differences in Time Domain (FDTD algorithm) and has taken into account evolution of FDTD and computing techniques of recent years. The robustness and reliability of this code has proved to be very efficient in industrial use.

Application domain

Applications of this code are 2D computations (bodies of translation) as well as real 3D bodies or periodic 3D bodies.

2D bodies currently computed are wings, coated or not with absorbing materials, details of structure like leading or trailing edges of wings or air intakes, cylinders of translation (sections of missiles), junctions between multilayers on metal substrate, and so on ...

In 3D, one can for example study electromagnetic behaviour of air intakes, entire missile at a low frequency, local scatterers like holes in the structure, periodic patterns such as dichroic devices. It can also take into account radiating devices such as patch antennas .

Computational domains extend from a few dozen l3 (l being the wavelength) to a few hundreds l3 in 3D for computations performed on workstations. The advent of computers with a high degree of parallelism now permits the computation of bodies with size up to several thousands l3 (entire missile at radar frequencies).

Input/Output

Geometrical input data for this code consist of a file containing the geometry of the body to be computed, in the form of meshes built from an INFOVISION(C) library model (Matra Bae Dynamics' software for geometrical computing) with a grid generator developed by Matra.

Other files contain the parameters of the computation itself such as frequencies,angles,size of meshes, polarization, output options, as well as the type of the excitation.

Output data are, according to the options, files containing monostatic or bistatic RCS in the desired polarization, reflection/transmission coefficients, fields/currents upon any predetermined surface in the computational domain.

The time domain properties of the code are fully used, and among other possibilities allow to get the RCS for a large range of frequencies in one single run (wideband pulse) , and to extract bright points from the total response of the object.
Post-processing facilities are available, allowing the visualization of results, especially fields and energies, which is an important feature for analysis of electromagnetic phenomena, along with time analysis.

Some validations and performances are presented at the conference.
The interest for industrial use of this code is underlined through some typical examples.

Validation of 2-D finite element predictions for multi-coated bodies.

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This paper will discuss the validation of a two-dimensional, time-domain, finite element model for EM wave scattering, developed at Sowerby Research Centre, British Aerospace, applied to multi-layered bodies composed of lossy dielectric materials. The code uses a Taylor-Galerkin
node-based scheme for time-advancing the fields, with an unstructured grid, and is used for RCS prediction.

As is well known, several calculational parameters may affect the accuracy of numerical codes of this nature: the grid resolution, the rate of change of element size across the mesh, the positioning and nature of the outer absorbing boundaries and the number of cycles within the
input pulse (for quasi-CW illumination). In addition, the modelling of objects with dispersive material properties requires care to ensure that broad-band predictions remain accurate.

With the aim of validating the 2-d finite element code we have developed analytic theories for the scattering of planar EM waves, of TE or TM polarisation, by multi-layered coated cylinders of circular and elliptical cross-section. The central coated core is assumed to be perfectly conducting in the circular cylinder model but may alternatively be any lossy or lossless material in the elliptical cylinder model. In both models the multiple coatings may themselves be lossy or lossless. For cylinders of circular cross-section the unknown field solutions are written as a sum of Bessel functions, with Mathieu functions being used for the elliptical case.
The code for cylinders of elliptical cross-section is found to be stable over a wide range of aspect ratios, allowing the code to be used to simulate a flat sheet. Far-field RCS can be calculated explicitly, in the frequency domain.

RCS predictions from the above analytical theory have been compared with those from the finite-element code, for a range of coated cylinders. We have found that agreement is excellent provided certain meshing criteria are observed (for example, a mesh density of around lambda/60 at the surface of the scatterer and lambda/10 at the outer boundary is typically required). Comparisons have also been used to determine the approach needed to model adequately the behaviour of wide-band pulse scattering.

Details of the analytical models, of the validation results and implications for the use of the finite-element code will be presented.

Session B02
Tuesday, July 14, AM 08:40-12:00
Room G/H
Tasks and Trends in Electromagnetic / Elastic / Wavefield Inversion

Organiser : D. Lesselier
Chairs : D. Lesselier, J. Bowler

Resolution and Super-Resolution in Far and Near-Field electromagnetic imaging

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The present paper deals with the assessment and the improvement of resolution limits in electromagnetic imaging problems. According to the classical point of view, the resolving power of a far-field imaging instrument or experiment is given by the so-called Rayleigh distance, i.e. half the wavelength of the probing radiation. This concept has to be revised for modern devices, insofar as they are computer-assisted and hence enable us to numerically invert the recorded image data in order to recover the probed object with increased resolution. In such a framework, the resolution limits no longer appear as a universal rule but instead as a practical limitation due to noise amplification in the data inversion process. Accordingly, they will depend on the available signal-to-noise ratio and also on the available a priori knowledge about the unknown object function. We show how to assess the actual resolution limits in a given imaging experiment, as a function of the noise level and of such knowledge.

A priori knowledge of the support of the object is of particular relevance for improving the resolution limits since it allows to increase the band of usable frequencies through some 'out-of-band extrapolation'. In such a case, it is possible to achieve 'super-resolution', i.e. subwavelength resolution. Quantitative estimates show nevertheless that significant super-resolution can only be achieved in the case where the space-bandwidth product is low, i.e. when the support of the object is smaller than the wavelength of the illuminating radiation. Such a condition is naturally met in scanning instruments and we provide examples of resolution gains attained in such a way.

Another way to overcome the diffraction limit of half a wavelength is to make use of the information conveyed by evanescent waves and contained in near-field data. A good laboratory for assessing the resolution limits in near-field imaging is provided by the so-called inverse diffraction problem. Spectacular super-resolution rates can then be achieved, which hold true also for more complicated near-field imaging devices such as microscopes, even if for most of these recent techniques a good direct mathematical imaging model is still lacking.

To conclude the paper we will address a few challenges in the field, as for example the usefulness of wavelet bases for getting adaptive super-resolving algorithms.

Decomposition of the Time Reversal Operator as Tool for Electromagnetic Sensing

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In Optics, if a source is spatially localized, phase conjugation mirrors have the property of focusing the reflected beam back on the emitter. If one considers that the scattered field is « emitted » by a scatterer, it may be conjectured that after reflexion on a phase conjugation mirror, the scattered field is focused on the scatterer. This idea has been developed, both experimentally and theoretically, for acoustic waves. It has also been developed, both experimentally and theoretically, for acoustic waves. It has been extended to transient regimes to focus ultra-sonic pulses on targets [1].

Some results are interprested using the notion of time reversal operator, which is built from measurements of the field on a surface for a set of incident waves. It is shown thet the eigenvalues and the eigenvectors of this operator contain some information about the number of scatterers and their location respectively [2]. With the aim of reconstructing the shape and/or the permittivity of a hidden object, this information is of course very useful if a description of the embedding medium is available. In this case the phase conjugation can be done numerically.

In partical applications, the description of the time reversal operator is linked to the experimental set-up, namely the spatial distribution of sources and receivers. First, we have studied the most favourable case where the domain under investigation can be surrounded by the antennas, in a two-dimensional configuration : s or p polarized cylindrical waves are impinging on cylindrical scatterers. A rigorous computation of the scattering problem is achieved, and several parameters arevaried : size of the scatterers, distance between them and polarization. It is shown that the distribution of eigenvalues is linked to that of the amplitudes of the scattered field in a Fourier-Bessel expansion. This basic result explains why in the low frequency range the s polarization is well suited : indeed, since the main contribution to the scattered field comes from the isotropic term, the time reversed wave is »isotropically » focusing on the target. But as expected, when two scatterers are close together, their interaction modifies the eigenvalues and the eigenvectors and may prevent their separation. To improve the spatial resolution, it may be helpful to vary the frequency or to change the polarization.

Finally, we discuss the interest of this method for providing an initial guess in a classical optimization algorithm, based on boundary integral method. Here, it is very important to know how many scatterers are lying in the domain under study.

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On the Retrieval of Simplified Objects in Wavefield Inversion

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The science of wavefield inversion can be understood as the nondestructive characterization of media and/or structures (an object) interrogated by a probing radiation (electromagnetic, acoustic, or elastic). Since the resulting wavefield contains some information about the object, the inversion is the procedure by which the observed part of this wavefield is transformed into intelligible information.

Typically, the authors and co-workers have been involved in such problems of inversion wherein the goal is to determine characteristics of scattering objects including shape, location, orientation and constitutive parameters from measured scattered field data resulting from known incident waves. Many solution methods have been developed for that purpose (spectral methods, modified gradient, complete family, level set, simulated annealing, etc.). In general such methods amount to finding a minimum of an appropriate cost function which measures the conformity of the response of the test object to that of the original object. At best, this cost function reflects the fit between the data and the wavefield associated with the test object, the satisfaction of the field equations, and the user's available information, or expectation.

However one may ask whether an exact copy of the object is required, and whether such a copy can be constructed in a realistic time frame, with keeping in mind that if the same numerical modeling is used to generate synthetic data as well as to invert them, one may create many solutions at least one of which is a good copy of the object.

Indeed, if one looks at the demanding applications of inversion tools, such as the retrieval of objects in natural media (shallow water acoustics, ultrasonic medical imaging, induction geophysics, ground probing radar) or man-made ones (eddy current and acoustic evaluation of metal and composite structures), from data that are often limited in space (with respect to the position of the sources and/or sensors) and in frequency, and probably incomplete (particularly critical may be the lack of phase), restriction to more modest goals may be appropriate.

For example, instead of attempting to reconstruct the fine geometric features of a boundary or the precise index of refraction everywhere, one may look for a few distinguishing features such as volume, location of an interior point, average and/or maximum value of refractive index, or number of distinct components. And, at a higher level, the search for one Simplified Object (SO) —or collection of SO— might be a good strategy if certain conditions are fulfilled: the availability of analytical solutions for such SO, the limited number of SO features, the fact that, once retrieved, these features still contain useful information. Examples include the so-called Intersecting Canonical Body Approximation applied to the characterization of a scatterer in a free or confined space, and Rayleigh series expansions of the wavefield identified as those due to an equivalent ellipsoid.

Subsurface Imaging Algorithms In Archaeology

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The key point of the confidence of non-linear inversion have been addressed and two algorithms have been analyzed. The first one is based on a quadratic approximation of the mathematical relationship between the data and the unknowns [1]. The second one is called bilinear method [2]. Both have been applied to the inverse scattering problem by pointing out the relevance of the 'information content' of the data in the non-linear case and essentially amount to minimizing a non-quadratic functional. Therefore deep attention has been devoted to considering the presence of local minima where the solution algorithm could converge to starting from an arbitrary point [3]. The theoretical results and the numerical experiences have confirmed the crucial role of the number of the available equations with respect to the number of the unknowns. Results will be shown at the Symposium.

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Shape and Profile Reconstruction of Two-Dimensional Dielectric Objects

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Among the available methods for reconstructing dielectric objects from known field information, two categories can be distinguished. Both categories have in common that the unknown object is characterized by a finite set of parameters. In the 'conventional' approach, the field is a 'dependent' quantity which, for each estimated configuration, is determined by solving the relevant direct-scattering problem. The optimum value of the configuration parameters is found by minimizing a cost function involving the difference between computed and available field information. In 'modified' approaches, the field is treated as an 'independent' quantity, and the cost function also contains the residual in the integral equation describing the direct-scattering problem. This has the advantage that the field and the configuration parameters are computed with comparable accuracy throughout the iterative minimization.

Because of this advantage, the latter category has received most of the attention in the recent literature. However, two developments can be observed that could shift this attention back towards the former approach.

In [1], several ideas are combined to solve the contrast-source integral equation for the scattering of an electrically polarized incident field by a 2D lossy dielectric cylinder. The space discretization is second-order accurate, and is capable of handling boundary as well as profile information. The convolution-type structure of the continuous equation is preserved in the discretized version, which allows the application of the CGFFT method. Moreover, a special extrapolation procedure is used to generate the required initial estimates. As a result, the computation time for determining the complete scattering operator becomes comparable to that for solving a few individual direct-scattering problems.

Both in inverse scattering and in antenna design, there is a renewed interest in determining the gradient (Fréchet derivative) of the cost function with respect to the configuration parameters [2,3,4]. The availability of the complete scattering operator opens up the possibility of first computing a single gradient function. Once this function is known, the gradient of the cost function can be obtained by evaluating a series of integrals over either the boundary or the interior of the estimated configuration.

These developments have raised the idea with the participating teams to develop an iterative inversion scheme of the 'conventional' type for the simultaneous reconstruction of the shape and profile of a two-dimensionally inhomogeneous dielectric cylinder. At the time of submission of this abstract, the implementation has just started. In the presentation, the basic ideas will be described and the available numerical results will be presented and discussed.

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The Far-Field Expansion Theorem in Biot's Thermoelasticity

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A thermoelastic wave, propagating in a homogeneous and isotropic medium, in the absence of body forces and heat sources, is scattered by a smooth, convex and bounded 3-D obstacle. Generalized Kupradze's radiation conditions are assumed to hold at infinity, which secures a unique solution for the scattering problem.

It is well-known that the behavior of the scattered thermoelastic field, away from the scatterer, exhibits the form of an outgoing spherical wave. In contrast to the classical elasticity, where the decrease in amplitude is described by the Hankel function and is of geometrical nature, corresponding to dimensional attenuation, in linear thermoelasticity the additional exponential decrease in amplitude, which appears in all but the transverse component of the displacement field, is of physical character and reflects the loss of mechanical energy according to the second law of thermodynamics.

The present work deals with the development of uniformly and absolutely convergent expansions for the three displacement fields (elasto-thermal, thermo-elastic and transverse) as well as for the two temperature fields (elasto-thermal and thermo-elastic) in the region exterior to a sphere circumscribing the scatterer.

These expansions are involve inverse powers of the radial distance from the center of the sphere. All the unknown coefficients involved in the expansions are expressed through recurrence relations as functions of the leading —zeroth order terms— coefficients, known as radiation patterns. More precisely, only four out of eleven zeroth order terms are needed for the complete reconstruction of the scattered thermoelastic field from its radiation pattern. These four terms correspond to the normalized scattering amplitudes of the displacement field, i.e. the radial elasto-thermal and thermo-elastic displacement amplitudes and the two components of the tangential displacement amplitude. The pure elastic case is recovered as the special case where the coupling constants tend to disappear.

Thin-Skin Eddy-Current Inversion for the Determination of Crack Shapes

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An eddy-current probe used for nondestructive testing undergoes a change of impedance when it interacts with a defect in a conductor. The impedance variation with probe position has been calculated for a surface crack excited by a time-harmonic field whose skin-depth is much smaller than the crack size. It is convenient to formulate the forward problem using transverse electric and transverse magnetic potentials defined with respect to the direction normal to the crack face. Assuming that the crack opening is small, there is very little perturbation of the electric field tangential to the crack which means that the field-crack interaction can be approximated in terms of a transverse magnetic potential alone. At arbitrary frequencies, the TM potential at the surface of a planar crack satisfies the Laplace equation in a domain corresponding to the crack face. Although boundary conditions are not available for the general case, they have been found for the thin-skin regime. Using the thin-skin boundary conditions solutions can be found by standard techniques including, for example, conformal mapping. Predictions of the probe impedance due to cracks are calculated from solutions of the Laplace problem and have been compared with experiment showing good agreement.

In the corresponding inverse problem, the aim is to determine the crack shape from observations of probe impedance. A least squares optimisation scheme using gradient methods is adopted for this task in which a provisional estimate of the geometry is progressively modified until the predictions of the forward problem match the observations. The key to the success of such iteration schemes is the calculation of the gradients. Specifically we seek the variation of probe impedance with respect to a variation of the crack profile expressed as a functional gradient. Researchers often refer to this as the sensitivity function because it represents the sensitivity of the observations to a change in the object. In this case, an incremental change in the crack profile gives rise to a change of the probe impedance. An analysis of these changes for the thin-skin regime shows that the functional gradient is determined by the magnetic field at, and tangential to the crack edge. Estimates of geometry, calculated by the inversion of impedance measurements, have been compared with measured profiles for a number of slots in aluminium plates. The comparisons show that thin-skin eddy-current inversion provides a good estimate of the shape and size of a crack.

Experimental Verification of Super-Resolution in Nonlinear Inverse Scattering

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The super-resolution phenomenon of nonlinear inverse scattering method using the distorted Born iterative method has been reported previously using numerically simulated data. What was shown was the ability of a nonlinear inverse scattering method to resolve features that were much less than half a wavelength, the criterion dictated by the Rayleigh criterion. The phenomenon has been attributed to the multiple scattering effect within an inhomogeneous body. The high spatial frequency (high resolution) information of the object is usually contained in the evanescent waves when only single scattering physics is considered. Multiple scattering converts evanescent waves into propagating waves and vice versa. Hence, in an inverse scattering experiment, even though an object has to be interrogated with a propagating wave, and that only scattered waves corresponding to propagating waves can be measured, the scattered waves contains high resolution information about the scatterer because of the evanescent-propagating waves conversion. Therefore, an inverse scattering method that can unravel the multiple scattering information can extract the high resolution information on a scatterer. In this talk, we describe a careful inverse scattering experiment, whereby scattered fields are collected by a switched Vivaldi antenna array of a time-domain ultra-wideband imaging radar system recently developed at the University of Illinois. The antenna array consists of five transmitters and six receivers. All the eleven antennas of the array are focused at the range of 40 cm. The test scatterers are put close to the focused zone. The distance between the scatterer and the antenna array is large enough so that only propagating waves are collected. The experimental data are processed with the distorted Born iterative method (DBIM), and show that it can resolve features smaller than the half-wavelength dictated by the Rayleigh criterion. Moreover, we demonstrate that DBIM can recover information on the backside of the scatterer even though scattering data are collected only from a limited viewing angles of the front side of the scatterer. This is also a consequence of extracting information from the multiple scattering physics inherent in the data collected, and is not possible in inverse scattering method where only single scattering physics is assumed.

Inverse Scattering for Dielectric Objects Using the Nonmeasurable Equivalent Current Density Inside the Scatterers

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The main drawback of many inverse scattering procedures is their inability to reconstruct (from measurements) some components of the equivalent current density inside the scatterers, so that the solution obtained may be too inaccurate (in many realistic cases it suffers of a strong low-pass effect). From a theoretical point of view this fact is related to the possible presence of the so-called nonradiating currents. More generally, in a discretized case with a limited measurement domain, we can refer to nonmeasurable currents, in the sense that the inverse mapping from the measurement space to the current space covers only a subspace of the currents; therefore, only those components that are inverse-mapped can be reconstructed.

Actually, there are many reasons that may combine to make a current component nonmeasurable: besides nonradiating currents, which provide a field that is exactly zero outside the scatterer, there may exist some components of the scattered field that are evanescent so that, in practice, they do not contribute to the field at the measurement points. Furthermore, if the measurement points are not properly placed, one may have two or more measures carrying almost the same information, thus giving rise to instabilities in the solution. It is also worth noting that this is one of the reasons that would make the idea of placing an arbitrarily large number of measurement points around the scattering domain impractical. Measurements can only provide a limited amount of information about the scattering domain, and such information is related to the so-called "degrees of freedom" of the problem.

In order to overcome this drawback, it seems mandatory to resort to nonlinear modeling, as it is suggested by the recent literature on inverse scattering and microwave imaging.

In this paper, in particular, a nonlinear procedure which tries to take into account the components on the equivalent current density that cannot be reconstructed from the measurement of the scattered field is presented. The approach is based on the reconstruction of the radiating (or, in general, of the measurable) components of the equivalent current density, by means of a singular value decomposition (SVD) of the discretized Green operator. Such components are then inserted into a nonlinear equation whose unknown are the nonmeasurable components as well as the dielectric features of the body under test.

In order to test the effectiveness of the proposed approach, some numerical simulations, concerning the reconstruction of circle cylinders, were performed. Numerical results show a dramatic improvement in the solution with respect to usual methods. In particular, both the value of the object function and the contour of the object can be reconstructed to a very high degree of accuracy.

Session C02
Tuesday, July 14, AM 08:40-11:00
Room I
New and Efficient Methods for Computational Electromagnetics

Organiser : J. M. Rius

Chairs : J. M. Rius, J.R. Mosig

TM' Scattering from Conducting Structures Utilizing Finite Elements in the Time Domain

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The objective of this talk is to use the finite element method in the time domain for the analysis of transient TM scattering from conducting structures. Here, the finite element method has been applied in the Time Domain. The differential equations are solved with a marching-on-in-time solution technique based on the Newmark's method. Newmark's method guarantee a stable marching on in time solution technique as long as certain parameters are within certain bounds. the marching on in time using Newmark's method and the discretization in space using the finite element method are the salient features of this technique. Use of the finite element spatial discretization necessitates the termination of the finite element mesh at a finite distance from the structure. a radiation condition is used to terminate the finite element mesh where an integral over time needs to be performed. The procedure uses a radiation condition. However, since it is a marching-on-in-time solution procedure values for the current exist for all the earlier times. Hence, it is quite straight forward to evaluate the integral to establish the radiation condition. In addition, since the radiation condition is based on the Green's function, the method is not approximate but numerically exact.

The talk will present numerical results for conducting structures based on the TM formulation. Comparison will be made with other methods like the integral equation method to compare the accuracy and the efficiency of the method. Another advantage of this method is that method is that the results are not unstable for late times. In summary, the method retains the simplicity of marching-on-in-time and utilizes the finite element method. In addition,the radiation condition is enforced in a numerically exact fashion.

Usage of Hilbert Matrices in the Reduced Expansion and Field Testing (REFT) Method for Matrix Thinning

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The REFT (Reduced Expansion and Field Testing) method has been recently refined (Steinberg and Kastner, Proc. 1997 URSI meeting, July 13-18, pp. 76), as a systemtic proceduren whereby the active number of both testing and basis functions is reduced to a minimum. To facilitate this reduction, both column and row operations are carried out by using the linear transformation $\mathbf{B}\cdot\mathbf{A}\cdot\mathbf{B}^T\cdot\mathbf{V}=\mathbf{B}\cdot\mathbf{E}^{inc}$, where the unknown current distribution is $\mathbf{J}=\mathbf{B}^T\cdot\mathbf{V}$, and $\mathbf{B}$ is a member of the Hilbert matrix family of orthogonal matrices, and whose elements are either 1 or -1. Matrices of higher orders are generated recursively from low orders as follows :

$$H_{2^{n+1}} = H_{2^n} \otimes H_2$$

where $\otimes$ is the Kronecker tensor product. The lowest order matrix is

$$H_2 = \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}, \text{ such that } H_4 = H_2 \otimes H_2 = \left(\begin{array}{cc|cc} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ \hline 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{array}\right),$$

$$H_8 = H_4 \otimes H_2 = \left(\begin{array}{cccc|cccc} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 \\ \hline 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{array}\right),$$

and soon. Hilbert matrices have the property $H_N \cdot H_N = NI_N$ i. e., the matrix $\frac{1}{\sqrt{N}} H_N$ is unitary. The also form the basis for the Walsh-Hadamard transform. Using this transformation, the matrix $\mathbf{B}\cdot\mathbf{A}\cdot\mathbf{B}^T$ can be thinned by about 90%, using a suitable threshold. The fer field accuracy is excellent in most cases, however the near field has an additive, non-radiating error. This error can be reduced, as preliminary results show.

Efficient Techniques for the Electromagnetic Analysis of Passive Microwave Components using the Admittance Matrix Representation

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Admittance parameters are widely employed to characterize the electromagnetic behaviour of arbitrary planar waveguide junctions, since they lead to very precise results obtained in a very efficient way. Even though strong efforts have been devoted to increase the simpleness and efficiency of procedures for evaluating such parameters, it is still very important to reduce the computation time required for the analysis of waveguide systems, in particular when they become more complex. In this paper, a simple and very fast method for computing the admittance parameters of planar waveguide junctions is first described. The key feature of this procedure consists on extracting the frequency dependence of all infinite summations related to the computation of some admittance parameters, thus only requiring to evaluate a few terms at each frequency point.

Once the calculation of admittance parameters has been optimized, it is interesting to notice that for the analysis of microwave devices composed of cascaded sections of uniform waveguides, the solution of linear systems is always required. Using the admittance matrix representation for describing waveguide junctions, a system with a banded coefficient matrix is obtained. This paper presents an efficient procedure for the solution of such banded linear systems, based on an iterative technique which exploits the structure of the coefficient matrix. A comparative study between this new procedure and two other common techniques is also offered, confirming that the technique proposed in the paper is indeed very effective.

After validating these two new procedures, they have been applied together to the analysis and design of complex microwave devices, such as inductively coupled rectangular waveguide filters including tuning screws and dual mode filters frequently used in the payload of communication satellites. The full wave electromagnetic analysis of this kind of devices has traditionally required an important computational effort, which has been substantially reduced by using the efficient techniques described in this paper.

Hybrid Method Based on a Generalized Admittance Matrix Representation

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In Computational Electromagnetics there exists a great number of numerical techniques to solve for electromagnetic problems. Some of these techniques are well known versatile methods such as Moment Method (MM), Boundary Element Method (BEM), Finite Element Method (FEM), FDTD Method, etc. Some other are more specific ones such as Mode Matching, GTD, etc. In many situations only one of these methods is enough to cope efficiently with a particular problem. However the growing complexity of problems and structures currently faced, demands the combination of different techniques to solve them. Such mixed techniques are commonly known as Hybrid Methods. Some classical examples of these methods are the Unimoment Method and the MM-GTD technique for free space problems. Guiding structures have also been analyzed combining modal expansions with BEM or FEM.

Most of the previously quoted methods are used to solve for boundary valued problems. Using uniqueness theorem and the equivalence principle such techiques can be reformulated to generate a generalized inmittance matrix characterizing the space enclosed in that boundary regardless the outer environment.

This paper deals with the segmentation of electromagnetic problems in suitable regions and the characterization of those regions by their generalized matrices (admitance, impedance or scattering). These matrices are obtained using the method which best adapts to the electrical and geometrical properties of each region. Both free space problems and guiding structures are considered using a unified approach. Once the analysis has adopted an algebraic form, all the power of circuit theory can be readily introduced to solve for the problem.

Such description of an electromagnetic problem is very attractive for developing CAD tools: a number of regions can be analyzed separatedly to buil up a library reducing the computational effort.

Several examples will be presented. Firstly, scattering and antenna problems (2D Cassegrain multireflector and horns) are analyzed through a spatial descomposition technique and an iterative algorithm. Secondly, Electromagnetic coupling through apertures in a cylinder is also considered. Finally A full wave S-parameter characterization of a set of dielectric posts in waveguide has been analyzed using the scheme summarized.

Impact of a Fast Wavelet Transform Approach on the Effective Design of Planar Antennas

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This paper discusses the efficiency of a direct Fast Wavelet Transform (FWT) approach applied to the design of planar antennas and arrays embedded in multilayered structures. The method is presented, developed and applied to some representative examples of planar antennas and arrays, reviewing its stability and accuracy in terms of S-parameters.

The antennas are analyzed by applying the Method of Moments (MoM) to the Mixed Potential Integral Equation, using Sommerfeld Green's Functions to represent the multilayered media: a triangular, non-uniform mesh is generated for the metallic surfaces. A Fast Wavelet Transform using a Daubechies Base is applied to the final form of the MoM matrix; the resulting matrix is thresholded and solved with conjugate-gradient. From the theoretical point of view, this "standard" approach suffers from different factors:

1) The mesh is 2-dimensional, while the wavelets used to transform the MoM matrix are 1-dimensional, thus generating a typical filter truncation effect in the matrix.
2) The concentration/thresholding procedure adopted opposes to the accurate modeling of the resonant currents in the radiating patches, highly sensitive to the modification of even the smaller elements in the MoM matrix.

The wavelet solution is tested against the design requirements of the planar antennas considered: S-parameters, operating frequency and bandwidth. Fig. 1(a) shows the $|S_{11}|$ parameter computed with different threshold levels (and the sparsity of the matrix),and Fig. 1(b) the running times of the code with respect to a no-FWT code. The test case considered is a 4-patches array, connected to a central feed by a complex beam-forming network, represented by ~1000 basis and test functions.

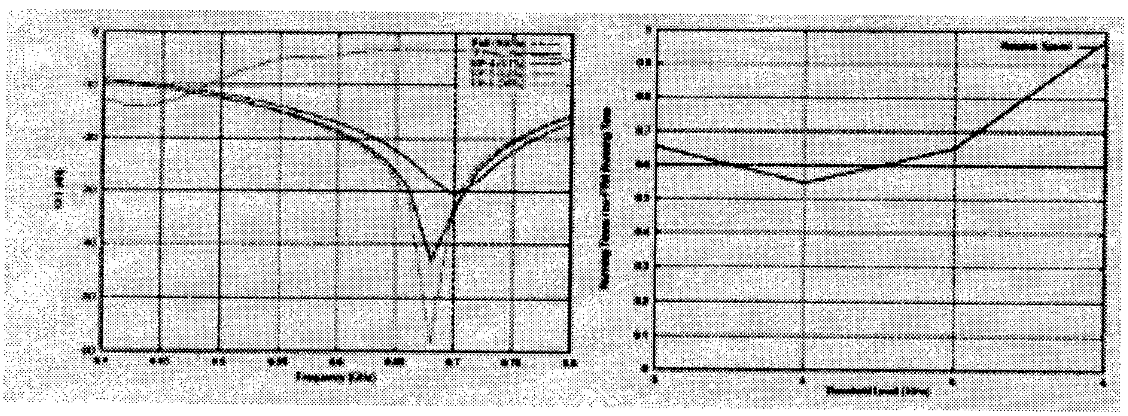

Figure 1: (a) $|S_{11}|$ of antenna and (b) running times of the relevant code.

The gain in terms of speed is significant, but limited by the number of iterations in the conjugate-gradient solution, increasing with the sparsity of the matrix. It is important to note that the threshold of 10^{-5} is optimal, preserving the accuracy of the design parameters. This is confirmed also by other tests, thus suggesting to use this level as automatic threshold.
Concluding, this direct FWT approach offers to the antenna designer already significant accuracy/speed performances compared to normal solutions, this for a reasonable price in the implementation effort.

The Integral Equation MEI for Three-Dimensional Scatterers

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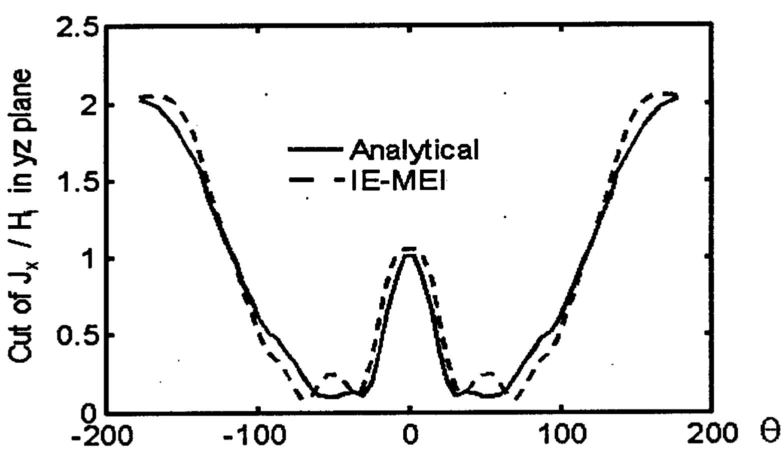
Boundary element methods (BEMs) are widely used for the numerical analysis of electromagnetic radiation and scattering. However, their application to three-dimensional (3-D) scatterers is limited to electrically small or resonant size objects due to the fact that the computational requirements increase rapidly with the electrical size.

Recently, several techniques have been proposed to reduce the computational cost of BEMs. These new techniques are commonly based on iterative solution of the system of equations, where the matrix-vector products are optimized either exploiting the physical or mathematical properties of the matrix or using sets of basis and testing functions that radiate narrow beams and thus produce almost-sparse impedance matrices. Most of this techniques share a common limitation: the application to 3-D arbitrary boundaries is difficult due to the use of analytically derived transformations that depend on the topology of the boundary.

A new approach, called the integral equation MEI (IE-MEI), is an approximate sparse matrix boundary element method in which the matrix coefficients are numerically derived (J.M. Rius, Elect. Lett., vol. 32, no. 1, pp. 23-23). This allows easy application to 3-D arbitrary surfaces. The IE-MEI memory and CPU time requirements are proportional to the number of unknowns in the surface discretization. Unfortunately, the method is applicable only to closed and convex surfaces.

The figure below shows the current induced on a sphere of diameter equal to two wavelengths discretized in 2048 triangles. Basis functions are Rao, Wilton and Glisson triangle pairs, with 3072 unknowns. The sparsity of the matrices is 4.5% and the memory usage is less than 8 MB. The IE-MEI computation is compared with exact spherical Bessel functions series, showing excellent agreement.



Session D02
Tuesday, July 14, AM 8:40-12:20
Room N
Computational Workshop
Organiser : A. Taflove

Session N01
Tuesday, July 14, AM 8:40-12:20
Room L
Antenna Arrays in Mobile Communications Workshop
Organiser : L. Godara

Session E02
Tuesday, July 14, AM 08:40-11:00
Room K
Wavelets in Electromagnetics
Chairs : P. Russer, R. Vauzelle

Time Domain Solution of Differential Equations Using Biorthogonal B-Spline-Wavelets

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A standard method for discretizing differential equations is the Petrov-Galerkin procedure. A linear combination of trial functions is used to represent the unknown functions and then the differential equation is tested by taking the inner product with an appropriate set of test functions. Wavelets exihibt some very nice properties: they are able to compress data (i.e. functions can be represented with fewer coefficients); the smoother a function is the faster its wavelet coefficients decay (this opens the possibility of adaptive algorithms without evaluating costly error functionals); and the matrix representations of some operators have uniformly bounded condition numbers. These properties make it very tempting to use wavelets as trial and test functions.

For time domain computations finiteness of the difference operators resulting from a Petrov-Galerkin discretization is very advantageous. Therefore we need wavelets with compact support. Also, since many problems are isotropic, the wavelets should be symmetric. The price one has to pay is orthogonality. We chose the biorthogonal, symmetric and real B-spline-wavelets designed by Cohen et. al. [1]. Calculating the scaling coefficients by applying Ware's projectors [4] and then using the fast wavelet transform yields the necessary expansion coefficients for initial values and for source terms.

After applying the Petrov-Galerkin procedure using B-spline-wavelets ---for linear differential equations, the necessary calculations can be carried out using the program written by Kunoth [3]--- one is left with a system of differential equations. To solve this system, one can choose an appropriate solver for systems of ordinary differential equations.

To check this idea, we investigated the application of biorthogonal B-spline-wavelets to telegrapher's equations. Results of numerical experiments including the use of different wavelets of the Cohen-Daubechies-Feauveau-family are presented. For time integration, the simple mid-point rule ---in conjunction with the modified Euler scheme to start the integration procedure--- is used.

The results indicate that to fully exploit wavelets, it is necessary to use fully adaptive algorithms, i.e. using not only scaling functions plus one wavelet level but five, six or more. To control the adaptivity, it is shown that a simple thresholding procedure is not sufficient.

Acknowledgement

We would like to thank Siemens AG for making this work possible by generously granting an Ernst-von-Siemens scholarship.

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The Wavelet Optimized Finite Difference Time Domain Method

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The finite difference time domain method (FDTD) has proven to be a powerful simulation technique in electromagnetic field computation. However, this technique suffers from a limitation that large amount of computer resources are needed to model the electromagnetic problem with large or medium volume.

One of the reasons for the large amounts of computer resources needed in traditional FDTD method is that uniform grid size is used to model the electromagnetic problems. The grid size is proportional to the minimum wavelength of the signal inside the whole solution domain under simulation. Therefore, shorter the wavelength, smaller the grid size, more the computer resources are needed. However, only the part of the signal, where the variation is large, needs a finer grid to model it. On the other hand, larger grid size is sufficient to model the smooth part of the signal. If uniform grid size is used to model the whole domain, part of the signal will be over resolved.

A wavelet optimized finite difference time domain method (WOFDTD) is proposed to reduce the number of grid point by using adaptive grid size, which is determined by the wavelet method. The WOFDTD method uses Daubechies-based wavelet method to refine the grid size. The wavelet functions can detect the oscillations in a signal at any location and scale. The signal decomposes into a set of wavelet coefficients, which depend on two parameters, one for location ' k ' and one for scale ' j ', d^j_k. If the magnitude of a wavelet coefficient is larger than a certain threshold, a grid size corresponding to scale j will be set at location k. That is, small grid size will be used where the variation of signal is large and larger grid size will be used where the signal is smooth. The WOFDTD method applies the conventional finite difference on the grid defined by wavelet functions. The grid size will be changed following the changing of the signal during the whole simulation. Using this approach, the signal will be modeled by a suitable resolution and the number of grid point can be reduced to the minimum. Therefore, the computer memory needed and computation time of the simulation can be reduced.

A Wavelet Operational Method for Solving Partial Differential Equations

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This paper extends the Haar wavelet operational matrix of integration originated by the authors and Hsiao to the normalized form and based on which establishes a method for solving linear partial differential equations. The advantage of the method is to convert partial differential equation solution problems into algebraic matrix multiplications and additions via Haar wavelets. Naturally, the approach is a computer oriented one. Four steps are listed as follows :

Step1 : For a linear partial differential equation, the following solution form is assumed.

$$y(x,t)=\sum_{i=0}^{\infty}\sum_{j=0}^{\infty}C_{ij}\hat{h}_i(x)\hat{h}_j(t) \tag{1}$$

where $C_{ij}=\int_0^1 y(x,t)\hat{h}_i(x)dx\cdot\int_0^1 y(x,t)\hat{h}_j(t)dt$

and $\hat{h}_i(x)$, $\hat{h}_j(t)$ are normalized Haar wavelet functions. The matrix form can be written as

$$Y_{m\times m}(x,t)=\left[\hat{h}_0(x)\quad \hat{h}_1(x)\quad \ldots\quad \hat{h}_{m-1}(x)\right]C_{m\times m}\cdot\left[\hat{h}_0(x)\quad \hat{h}_1(x)\quad \ldots\quad \hat{h}_{m-1}(x)\right]^T \tag{1a}$$

or $\quad Y_{m\times m}(x,t)=\hat{H}_m^T(x)\cdot C_{m\times m}\cdot\hat{H}_m(t)$; or $Y_{m\times m}(x,t)=\hat{H}_m^{-1}(x)\cdot C_{m\times m}\cdot\hat{H}_m(t)$ (1b)

where $Y_{m\times m}$ and $\hat{H}_{m\times m}$ are matrix forms of $y(x,t)$ and normalized Haar wavelet set respectively.

Step2 : The Haar wavelet matrix of integration is easily derived as follows :

$$P_{m\times m}=\left[\begin{array}{c|c|c|c} m^2 & -(\frac{m^2}{2})H_1 & & \\ \hline (\frac{m^2}{2})H_1^{-1} & 0 & & mH_{\frac{m}{2}} \\ \hline & & 0 & \\ \hline & mH_{\frac{m}{2}}^{-1} & & 0 \end{array}\right] \text{ and } \hat{P}_{m\times m}=G_m P_{m\times m}G^{-1} \tag{2}$$

and $\int_o^t y(x,t)dt$, $\int_0^x y(x,t)dx$ and $\int_o^x\int_o^t y(x,t)dtdx$ becomes the following

$$\hat{H}_m^T C_{m\times m}\hat{P}_{m\times m}\hat{H}_m,\quad \hat{H}_m^T\hat{P}_{m\times m}^T C_{m\times m}\hat{H}_m \text{ and } \hat{H}_m^T\hat{P}_{m\times m}^T C_{m\times m}\hat{P}_{m\times m}\hat{H}_m \tag{3}$$

in which $G_m=\begin{bmatrix} 1/\|h_0(t)\| & 0 & 0 \\ 0 & \ldots & 0 \\ 0 & 0 & 1/\|h_{m-1}(t)\| \end{bmatrix}_{m\times m}$ and $\|h_i(t)\|=\sqrt{\sum_{k=0}^{m-1}h_i[k]}$ for $i=0,1,\ldots,m-1$

Step3 : By substituting (1) & (2) into the linear partial differential equation in question, a kind of Liapunov matrix equation is obtained. In the matrix equation, terms like those shown in the following formula appear:

$$\hat{H}_m^T\hat{P}_{m\times m}^T C_{m\times m}\hat{H}_m+\hat{H}_m^T C_{m\times m}\hat{P}_{m\times m}\hat{H}_m=\hat{P}_{m\times m}^T U_{m\times m}\hat{P}_{m\times m}+\cdots \tag{4}$$

where $U_{m\times m}$ is a matrix in which every element is unity.

Step4 : The coeffcient matrix $C_{m\times m}$ can be evaluated by using MATLAB subroutine «*lyap*». Then substitute $C_{m\times m}$ into (1b) and $Y_{m\times m}$ is obtained. Finally rewrite $Y_{m\times m}$ into $y(x,t)$ which is the answer.

Wavelet and Propagation Prediction for Mobile Radio Communications

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The purpose of the approach is to optimize the computation time required for foreseeing the coverage zone of a mobile communication transmitter by using a propagation model. Moreover, this approach allows to choose the optimum propagation model depending on the propagation environment. The wavelet analysis is at the heart of the method and allows to determine some information about the mechanisms of the wave propagation. When these are injected to a 3D geometrical analysis of the studied geographical zone, an important reduction of the computation time is obtained.

The proposed method splits up into two stages. The first one, based on the wavelet transform, gives parameters to the next stage, which leads to the determination of the coverage zone.

The principle of the first stage lies upon the application of a wavelet analysis of the discrete signals coming from a moving receiver. In mobile communications, the received signal is the sum of slow variations due to mask effects and rapid variations which respect to a Rayleigh's law or a Rice's law, which are due to multipaths. These two kinds of variations are identified according to the position of the moving receiver on a predefined way. This identification is the result of an exploitation of the wavelet transform of the measured signal in the low and high frequency octaves. The number of octaves to be considered is determined according to a decision criterion which depends on the precision of the desired final result. From this step we determine simultaneously the number of significant interactions (diffraction and reflection) undergone by the wave, and the probability density functions characterizing the combination of interactions along the path of the moving receiver. Those two information are the basic parameters of a 3D geometrical analysis of the propagation that leads directly to the determination of the coverage zone of a transmitter in a very short computation time.

Compared to a traditional method which consists in applying a propagation model according to a constant step in the studied zone, this efficient approach allows to reduce considerably the number of application of the model and to choose the optimum one.

Signal Processing of Data from Magnetic Flow Detector Devices Using Wavelet Transformation

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The safety of the people depends on the condition of steel ropes used in various transport or construction systems (rope ways, cable cars, underground transport systems in mining etc.). But the conditions of the ropes change during the time, so it is necessary to check them regularly. The most common method of the testing is visual inspection, which is suitable for small diameters, but for the greater ones is necessary to use other, more sophisticated methods. One of them is magnetic defectoscopy. This method allows us to detect not only the surface breakages, but the internal ones too.

The digitized flow detecting apparatus is completed from measuring head with optoelectronic incremental rotational gauge, indication module and computer.

The processing of the digitized signal is provided in two stages:
- baseline visualization methods,
- evaluation methods characterizing the state of the steel cable.

Among evaluation methods the wavelet transformation gives very hopeful results in signal processing and datum interpretation in the steel rope inspection. In our hardware equipment the signal detection is divided to two basic channels because the signals from corrosion and ones related to breakages and cracks are located in different frequency bands. We analyze in detail the possibilities of hard, self, quantile, and universal thresholding in the filtration processes for magnetic defectoscopy output signals. Effort is concentrated on the specification of optimum signal/noise relation in the corrosion channel and on signal deformation and modulation in the breakage channel. Concrete signal processing results with help of wavelet transformation for outputs signals from laboratory rope etalon and from practice measurements are presented and correlation between quality of steel rope sample and wavelet analysis is illustrated. The results show that the wavelet transformation enables us to solve the problems of the detection the internal wire breakages and cracks, mainly for greater rope and cable diameters.

Wavelet Approximation of Distributed Parameters Electric Line

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Let us consider the electric line which is described by a partial differential equation of the hyperbolic type

$$\frac{\partial y}{\partial t}+S\frac{\partial y}{\partial x}=Ay \tag{1}$$

where

$$S=\begin{bmatrix}\frac{-1}{\sqrt{LC}} & \\ & \frac{1}{\sqrt{LC}}\end{bmatrix} \qquad A=\frac{1}{2}\begin{bmatrix}-\frac{G}{C}-\frac{R}{L} & \frac{G}{C}-\frac{R}{L} \\ \frac{G}{C}-\frac{R}{L} & -\frac{G}{C}-\frac{R}{L}\end{bmatrix} \tag{2}$$

and R, L, C, G are distributed parameters of the electric line (resistance, inductance, capacitance and conductance, respectively). The dependent variable y is connected with the current i and voltage u by the following transformation

$$y=\frac{1}{2\sqrt{LC}}\begin{bmatrix}\sqrt{L} & -\sqrt{C} \\ \sqrt{L} & \sqrt{C}\end{bmatrix}\begin{bmatrix}i \\ u\end{bmatrix} \qquad \begin{bmatrix}i \\ u\end{bmatrix}=\begin{bmatrix}\sqrt{C} & \sqrt{C} \\ -\sqrt{L} & \sqrt{L}\end{bmatrix}y. \tag{3}$$

Let us assume that the electric line is supplied (on boundary $x=0$) by a real voltage source $u^b(t)$ with internal resistance R_b and let the load resistance on the other boundary $(x=1)$ be R_e. Under these assumptions we obtain the boundary condition

$$\begin{bmatrix}y^-(t,1) \\ y^+(t,0)\end{bmatrix}=\begin{bmatrix}0 & \frac{\sqrt{L}-R_e\sqrt{C}}{\sqrt{L}+R_e\sqrt{C}} \\ \frac{\sqrt{L}-R_b\sqrt{C}}{\sqrt{L}+R_b\sqrt{C}} & 0\end{bmatrix}\begin{bmatrix}y^-(t,0) \\ y^+(1,1)\end{bmatrix}+\begin{bmatrix}0 \\ \frac{1}{\sqrt{L}+R_b\sqrt{C}}\end{bmatrix}u^b(t) \tag{4}$$

where the dependent variable y is divided into two components y^- and y^+. From the distribution of current and voltage for the electric line at time $t=0$, the initial condition is known

$$y(0,x)=y_0(x) \qquad \text{for} \qquad 0\le x\le 1. \tag{5}$$

The Galerkin approximation of the solution of initial-boundary value problem (1),(4),(5) has the form

$$\tilde{y}(t,x)=Z(t)\varphi(x) \tag{6}$$

where $Z(t)\in\Re^{2\times n}$ is a solution of matrix ordinary differential equation

$$\frac{dZ}{dt}=AZ+S(Z_b+ZF)E^{-1} \tag{7}$$

and the vector $\varphi(x)\in\Re^n$ consists of the assumed compactly supported wavelet functions

$$\varphi_j(x)=\varphi^v\left((n-1)x/2-1-j/2\right) \tag{8}$$

at resolution $n=3,4,5,\ldots$ and translation $j=1,2,3,\ldots,n.$ Boundary conditions (4) are included to the matrix $Z_b\in\Re^{2\times n}$ and the constant matrices $E,F\in\Re^{n\times n}$ consist of the wavelet inner products and the inner products of wavelets and their first derivatives, respectively. The initial conditions for matrix equation (7) are calculated from initial conditions (5).

Session F02
Tuesday, July 14, AM 08:40-11:20
Room B/C
Microstrip Antennas and Planar Antennas
Chairs : G. Vandenbosch, C. Terret

Dynamic Method Applied in Planar Antenna Design

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In this work, the Transmission Line Model [1] is used in conjunction with the Transverse Transmission Line (TTL) [2] method in the analysis and design of the microstrip patch antenna. The microstrip patch antenna is the preferred choice for many applications in microwave and millimeter waves due its compact structure [3]. The TTL method is a full wave method and it is very appropriate for use with microstrip antennas, to obtain the effective dielectric constant with high precision, and the antenna parameters as efficiency, bandwidth, quality factor, radiation patterns are obtained with more accuracy.

Considering the microstrip rectangular patch antenna, as a session of microstrip line of width *W*, a set of equations that represent the electromagnetic fields in the **x** and **z** direction as function of the electric and magnetic fields in the y direction are obtained applying the TTL method. Two components are used to represent the electric and magnetic fields: the transverse (y) and tangential (t = x and z) components to the patch antenna, and after various algebraic manipulations the general equations for the structure in the Fourier Transform Domain (FTD) are obtained. After the application of the boundary conditions, the Moment method is applied to eliminate the electric fields and to obtain the homogeneous matrix equation. The roots of this matrix are the attenuation constant (α) and phase constant (β). The effective dielectric constant is obtained from $\varepsilon_e = (\beta/k_0)^2$, where k_0 is the free space wave number.

Results for the radiation patterns in the E-plane and H-plane, efficiency, η, bandwidth, BW, and quality factor, Q, are shown, and these values are more accuracy due the utilization of a dynamic method. This work was supported by CNPq and CAPES.

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The diffraction of surface and space waves at the truncation of a planar dielectric structure.

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Microstrip antennas are very widespread. The radiation pattern and input parameters are normally computed in the assumption of infinite substrate dimensions. The finiteness of the substrates leads to deterioration of the radiation pattern and changes also the input parameters. The direct way to take these effects into consideration involves the volume integral equations technique and as consequence it requires huge computer resources. An alternative way is based on the expansion wave concept. The main idea of this concept is that the field excited by any source after a certain distance from the source along the air-dielectric interface can be expanded into a limited number of surface and space waves. These waves propagate along the substrate up to the edge where they diffract and reflect. The knowledge of diffraction pattern and reflection coefficients permits to implement the finiteness of the substrate to existing software in a rather simple way by using the postulates of geometrical theory of diffraction. However the calculation of diffraction and reflection is not a simple task and it is the goal of this work. We investigate a semi-infinite truncated dielectric structure which is excited by surface or space waves. The structure is a ground plate covered at two sides by a multi layered dielectric. By using an equivalence principle it is possible to introduce an unknown surface magnetic current backed by a conducting wall in the plane perpendicular to the dielectric structure. Now the space is split into three regular regions where there are no truncations. The condition of continuity of tangential magnetic field components yields an integral equation for the magnetic current which is solved by the Galerkin method. The numerical calculation shows the stability of this solution. The proposed method is very agile and permits to analyse different kind of structures. These advantages are explained by the way in which we solve the problem. After the introduction of magnetic current the space is split into three independent regions. Each of regions is treated as a general multi layered structure. It can be free space, a parallel plate system partially filled with a dielectric or a multilayered dielectric with or without ground plate. So the number of real structures which can be analysed is rather large. For some of them a solution obtained by other methods is available. The good agreement in all cases shows the validity of our method.

The proposed method is simple and fast and it can be used to take into consideration the finite dimension of substrates for planar antennas.

Slot Antennas Fed by a Coplanar Waveguide

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A simulation method for slot antennas fed by a coplanar waveguide is presented. The computation is based on an integral equation solved by applying the method of moments. Pentahedral funcions are used as expansion functions for the equivalent magnetic current densities. Special half pentahedral functions have to be introduced in order to satisfy the edge and boundary conditions. In order to solve the problem, instead of the commonly used spectral domain solution of the reaction integrals, the spatial domain method is used. As computation time could be reduced significantly, it is now possible to simulate quite complex multilayered structures within a convenient time.

A modular approach has been chosen in order to model even complicated geometries including edges, t-junctions and other rectangular transmission line elements occuring in coplanar structures. The complete structure is divided into basis elements like corner elements or single straight lines. According to the boundary conditions, the pentahedral expansion functions have to be modified for each field component.

Several setups like slot antennas fed by a coplanar line have been simulated and realized in practical. The avoidance of the excitation of parallel plate modes is important in order to minimize unwanted radiation. The computational results including the field distributions, field patterns, gain and reflection coefficients are compared with measured results. Very good agreement has been achieved.

Theoretical and Experimental Analysis Microstrip Modular Antenna on Multilayer Dielectric

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This paper presents 3 antennas (one of them is working with vertical polarisation, the second one is working with horizontal polarisation, and the third one with rotary polarisation) in the form of modules which consist of radiators made in microstrip technology and working in a band 1.8 GHz. The radiators structure is discussed and the results of measuring its parameters are presented. The discussion of choice of module constructional dimension as well as its basic parameters and radiation pattern are also shown. The possibilities of modules application in antenna arrays is also discussed here.

The modules presented in the paper can be broadly used as a base construction in array antennas. Phase feeding was intentionally used in the modules.

The module consists of 3 parts :

- Feeding system
- Distribution power system
- Module of microstrip radiators made as multilayer technology with slot feeding.

The construction is universal because when there is an unchanging part of radiation we can electronically manipulate the change in antennas radiation pattern by changing the feeding system.

Using the multilayer construction allows to extend the band frequency over 15%. We can distinguish 3 layers in this construction : dielectric-air-dielectric. The radiating element is a rectangular printed on the upper side of the laminat lower layer. The slot is feeded by unsimmetrical microstrip line that has impedance of 50Ω.

The modules presented here can also be used in phased antennas arrays. In such a case the feeding system must be supplemented with a phase shifter. The process of designing antenna arrays requires the knowledge of coupling between the elements. The authors have developed an analytical methods to determine general impedance, and in effect self and mutual impedance microstrip antennas on a multilayer dielectric with an ideally conducting screen.

The method of moments with adequate choice of base and testing functions was used to design this module and to calculate the mutual coupling (mutual impedance). Calculations were made and they were compared with measuring results of these models. Great compatibility of this theory with the results of measurements was achieved.

Radiation From Arbitrarily Shaped Microstrip Patch Antennas Using the Theory of Characteristic Modes

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In the past years microstrip patch antennas and arrays have been widely investigated in the literature. Microstrip antennas have many applications as aircraft to satellite communictions and GSM communications. Also, they are attractive elements at microwave frequencies due to their advantages such as conformability and easy of manufacture.

In this work a Full Wave solution to the problem of radiation by arbitrarily shaped pach printed on a grounded dielectric slab, using the Theory of Characteristic Modes, is presented. The radiation properties of arbitrarily shaped patch are examined with a Spectral Domain Moment Method approach. The Galerkin solution presented use characteristic modes of the patch as basis functions to model current distibution on it.

The theory of characteristic modes for conducting bodies has been developed by Garbacz [1] and by alternative approach by Harrington and Mautz [2], [3]. The characteristic modes are entire domain basis functions that include the behaviour of the current and in principle can be computed for any antennas shape. They are applied recently in the analysis of scattering and mutual coupling by many metallic objects [4], [5].

Numerical results for several microstrip patches have been calculated. Computed current distribution on antennas and example of convergence are presented. Numerical data are compared with measurements and literature data showing a good agreement between them.

Because a small number of characteristic modes are necessary to yield a good approximation of the induced current on patch antennas, the proposed method seems promising for exact analysis of scattering and radiation from the arrays of microstrip patches, reducing the number of unknowns in the moment method solution and the correspondig computational effort.

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Broadband and Multifrequency Dielectric Resonator Antennas

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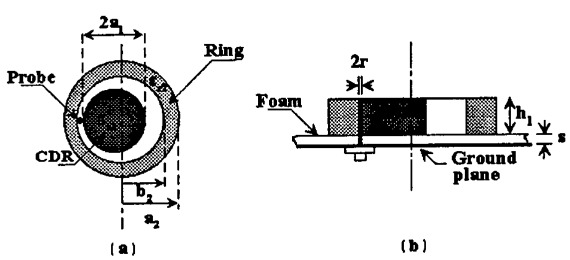
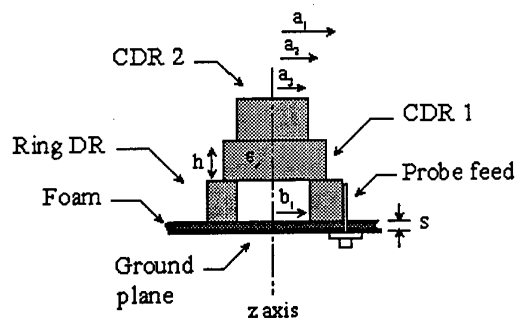
Numerical and experimental studies are presented for various DR configurations. Structures are analyzed numerically with a time harmonic surface finite element method (SR3D software developed by France Telecom / CNET [1]).

The characteristics studied for antenna configurations shown below include return loss, radiation patterns and antenna gain. The experimental results are reported in the table 1, and exhibit a good agreement with the numerical ones.



Embedded configuration



Stacked configuration

Antenna	Characteristics	Frequency Range (GHz)	10 dB Bandwidth (%)	Antenna Gain (dB)
Embedded configuration	Broadband	5.4 – 7.8	38	~ 6
Stacked configuration	Multifrequency	4.95 / 6.14 / 8.32	9.5 / 6.6 / 4.2	4 / 3.2 / 2.1

Table 1 : Experimental results

Radiation properties could be improved by suppressing unsuitable modes with thin wires parallel to the electric field. Results showing the influence of the suppression of mode will be presented, as well additional results of other arbitrarily-shaped antennas.

These antenna configurations could be used for different antenna applications needing large bandwidth, multifrequency and diversity radiation properties.

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Optimization of a 'YAGI-LIKE' Stacked Microstrip Dipole Array Using Evolutionary Programming

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A new class of multi-layer printed antenna structures have recently been proposed in [1] as a low-profile alternative to the conventional Yagi-Uda array of wire dipoles. Although the Yagi-array, which is widely used in communications and radar for high-gain applications, has a relatively simple structure made of thin-wire elements, its overall length could become very large for high gain and/or low-frequency applications mainly due to the large number of directors and the required spacing between the elements. In addition, a mast is required to structurally support the array elements in air. One of the proposed structures in [1] is a multi-layer printed microstrip version of the Yagi array of wire dipoles in air. This structure consists of a ground-plane reflector, a driver and a finite number of embedded director strip elements. The structure gives us a few more degrees of freedom in terms of the dielectric constants of the layers when optimizing its design. Previous attempts to optimize this Yagi-like structure for high gain, however, were arbitrary in nature and were done using a simple parametric study [1]. Nevertheless, it has been shown that a 3-layer structure with $e_r = 2$ can produce a gain as high as 10 dBi or more, indicating its potential for high gains. Further, the results in [1], which were obtained by applying a mixed-potential integral equation (MPIE) technique to model the antenna structure, indicate that the objective function relating the gain to the antenna parameters is highly non-linear and possess multiple local optima. To successfully optimize this structure global optimization schemes, such as evolutionary algorithms, are necessary.

Among the class of evolutionary algorithms, genetic algorithms (Gas)) have been widely used and are well known in the electormagnetic community. Conventional genetic algorithms require the continuous design parameters to be discretized and represented as binary strings for optimization. This could limit the accuracy of the solutions obtained. Further, improper selection of the initial population could cause the GA to converge prematurely to a non-optimal solution. An alternative technique is the evolutionary programming (EP) [2] which has been shown to be superior to GAs in a number of real parameter optimization problems. EP can directly work with the continuous parameters that are to be optimized. Unlike GAs which model evolution at the level of the individual, EP models evolution at the species level. As a result, recombination operators such as crossover are not used, but instead problem specific mutation operators are used. Problem specific mutation operators are relatively easier to design and facilitate easy integration with available apriori knowledge about the problem.

In this work, the microstrip Yagi array is represented as a vector consisting of the length of the driver element, the director lengths, the dielectric constants, and the dielectric thickness. In order to ensure that the optimized solutions obtained are practically feasible, a set of constraints on input-impedance, minimum dielectric thickness of each layer and maximum total thickness of the structure are chosen. The constraints are implemented by penalizing solutions that violated these constraints. In the optimization process the driver length is set to its resonance length to make the input impedance purely resistive where as the director lengths and dielectric constants and thickness of layers are optimized using EP. A population of trial vectors is maintained. A set of gaussian mutation operators are performed to produce changes in these vectors, and selection is used to determine which vectors are to survive to the next generation, and which vectors are to be culled from the pool of trials. This process is repeated until an acceptable amplitude weight vector is obtained, or the available computer time is exhausted. For the case of a 3-layer structure with $e_{r1}= e_{r2}= e_{r3} =2$, a gain of more than 12 dBi is obtained. Results of the optimizations involving 4 and 5 layer structures will be discussed in the presentation.

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Session G03
Tuesday, July 14, AM 08:40-10:00
Room M
Solitons and Non-linear Optical Fiber Transmission

Chairs : Ch. Rumelhard, Y. Boucher

10:00 ***Coffee Break***

Simulation of an WDM System Using SIMNT

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SIMNT is an application software for the simulation of optical communications systems. This tool makes use of recent technics for systems simmulation such as modular structure, open topology, devices and systems integration, difinition of feedback bolcks, programmable library of models, ordering and execution of the system. The SIMNT also suports na hierarquical definition of blocks, i.e., new blocks can be defined from those already created. Multiple instances of the same block are also allowed.

In this paper we present an application of SIMNT for the development and analysis of an WDM optical communication system. This system uses an IM/DD transmission mechanism. In this system, eight lasers are coupled to a fiber optical channel. Its simulation requires the following models: Current driver, DFB singlemode laser, singlemode fiber, photodetector PIN, Coupler, Gaussian filter and Fabry-Perot filter.

Figure 1 shows the eye pattern for the signal on the output of the gaussian filter. The closing of the eye pattern allows for a comparative evaluation of the increase of the error probability of the system.

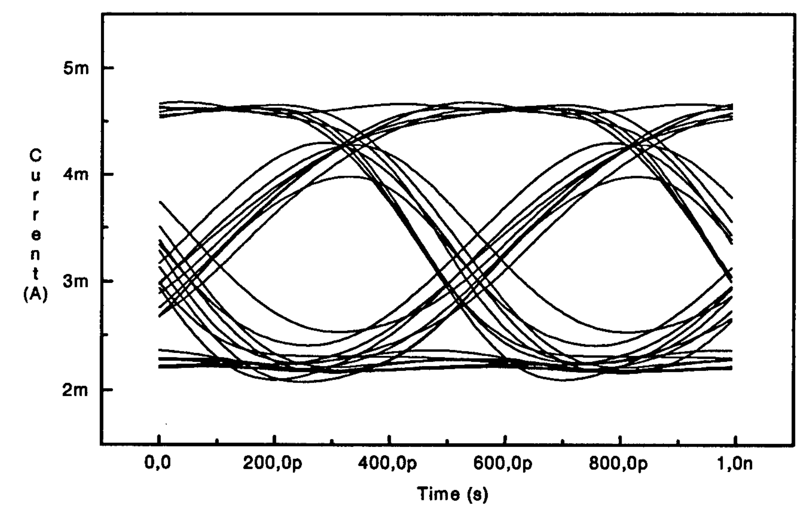

Figure 1 : Eye pattern generated with the signal on the output of a Gaussian filter; interchannel spacing of 12GHz; FWHM=10GHz.

Experimental verification of bit pattern effects obtained in numerical simulations of a 10GBit/s 1.3 µm optical communication system

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Throughout the last years the development of semiconductor optical amplifiers (SOA) operating at 1.3 µm has made progress towards its use in near-future optical communication systems. Taking advantage of the optical transparency of systems using optical amplifiers, signal transmission becomes independent from fixed bit rates so that fiber links, existing or to be deployed, can be used efficiently.

Due to the nature of the SOA, its carrier lifetime is relatively short which - in connection with a saturation energy in the order of pJ - gives way to bit pattern effects. We examine these bit pattern effects by simulating the transmission of a 10 GBit/s 1.3 µm NRZ signal over an installed fiber link of 150 km length between Darmstadt and Rödermark, Germany. Details like different parameters of each fiber span and amplifier, location of splices, optical filters and amplifiers are all included. We investigate the effect of varying signal power on the bit pattern due to varying saturation of the amplifiers.

In order to confirm our simulational results, we additionally measured the bit pattern effect during a field trial carried out at the Deutsche Telekom AG on the link described above, using the the same set of parameters. Experimental and simulation results are in very good agreement, revealing that our numerical model of the SOA is well suited for the prediction of pulse shaping in optically transparent high speed fiber links.

Erbium-Doped Nonlinear Fiber Coupler : Influence of Wavelength Mismatch on Soliton Switching

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In fiber-optic communication systems the bottlenecks caused by the conversion between optics and electronics can be avoided through all-optical switching. Due to their particlelike behavior, temporal solitons in nonlinear fiber couplers do not breakup – a property that makes them suitable for all-optical switching.

It has been shown that the use of an erbium-doped nonlinear fiber coupler not only reduces the critical power necessary for self-routing switching but increases the slope of the transmission curves as well [1]. However, the main drawback is the amplifier bandwidth. In this paper we analyze the influence of wavelength mismatch on self-routing soliton switching in an erbium-doped nonlinear fiber coupler.

Using the Ginzburg-Landau model [2], the nonlinear evolution equations for soliton switching may be written, in soliton units, as

$$i\frac{\partial u}{\partial \zeta}+\frac{1}{2}(1-id)\frac{\partial^2 u}{\partial \tau^2}+\left(|u|^2+\sigma|v|^2\right)u+\kappa v=\frac{i}{2}\mu\, u$$

$$i\frac{\partial v}{\partial \zeta}+\frac{1}{2}(1-id)\frac{\partial^2 v}{\partial \tau^2}+\left(|v|^2+\sigma|u|^2\right)v+\kappa u=\frac{i}{2}\mu\, v$$

where κ is the linear coupling coefficient, σ is the cross-phase modulation coefficient, μ is the normalized maximum gain and d accounts for gain dispersion. As shown in [3] these coupled equations can describe, within a unified framework, both twin-core fiber couplers and birefringent fibers (with linear birefringence).

For self-routing pulse switching we have considered the inputs

$$u(\zeta=0,\tau)=\sqrt{P_{IN}}\,\mathrm{sech}\left(\sqrt{P_{IN}}\,\tau\right)\exp(-i\xi\tau), \qquad v(\zeta=0,\tau)=0\,,$$

where P_{IN} is the input peak power and $\xi=\Omega\tau_0$ is the normalized frequency mismatch between the carrier frequency of the input pulse and the frequency corresponding to the atomic transition (*i.e.*, the frequency where the amplifier gain exhibits its maximum value). $\tau_0=0.567\tau_S$ where τ_S is the soliton pulse width (FWHM).

We have analyzed the influence of the frequency mismatch on the switching characteristics – namely, on the critical power and on the transmission coefficient. We have also studied the frequency shift caused by the amplifier bandwidth.

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Wavelength - Division Multiplexing with Solitons in Erbium-Doped Fiber Amplifiers

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One of the most important problems associated with lightwave systems is the so-called rise- -time budget. Several dispersion-compensating techniques have been developed to overcome the dispersion limitation of optical fibers. However, the best solution to this problem is probably the use of solitons in what has been termed the fifth generation of fiber-optic communication systems [1, pp. 4-7]. The capacity of a lightwave system can be considerably increased by using *wavelength-division multiplexing* (WDM). Hence WDM soliton systems [2] constitute one of the most promising techniques for optical communications [1, pp. 516- -524].

Doped-fiber amplifiers and, in particular, *erbium-doped fiber amplifiers* (EDFAs) are widely used to provide lumped or distributed amplification in fiber-optic communication systems [1, pp. 391-403]. In this paper we analyze the propagation of a WDM soliton system inside an EDFA. Using a generalized nonlinear Schrödinger equation known as the *Ginzburg--Landau equation* (GLE) [3], our main goal is to find an upper limit to the number N_{ch} of WDM channels.

Neglecting two-photon absorption and gain saturation, the GLE may be written in normalized units as [4, pp. 494-515]

$$i\frac{\partial u}{\partial \zeta}+\frac{1}{2}(1-id)\frac{\partial^2 u}{\partial \tau^2}+|u|^2 u=\frac{i}{2}\mu\, u$$

where d is related to the amplifier bandwidth and μ to the amplifier gain. Using the numerical algorithm known as the split-step Fourier method [4, pp. 50-54], we have considered an input

$$u(\zeta=0,\tau)=\operatorname{sech}(\tau)\exp\left(i\frac{\kappa}{2}\tau\right)+\operatorname{sech}(\tau)+\operatorname{sech}(\tau)\exp\left(-i\frac{\kappa}{2}\tau\right)$$

where κ is the normalized frequency separation between the two outermost channels of the WDM system. Imposing the criterion that the amplitude of the outermost channels should not be less than $1/\sqrt{2}$ of the amplitude of the central channel, we have determined a maximum value for κ: $\kappa_{\max}$. Hence, if $\kappa_{\min}$ is the minimum frequency separation to avoid spectral overlapping, one has $N_{ch}=\kappa_{\max}/\kappa_{\min}$. The results thus obtained were then compared with those obtained through the Maxwell-Bloch equations including the nonlinear effect of gain saturation.

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Session G04
Tuesday, July 14, AM 10:20-12:40
Room M
Microwave Components I

Chairs : S. Toutain, H. Baudrand

Implementing Transmission Zeros in Broadside Coupled Microstrip Filters

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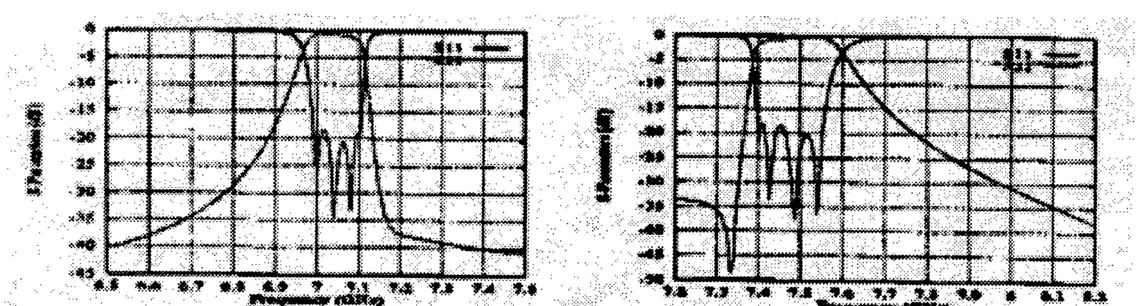
The development of microwave filters remains a very important activity in many communication applications and great effort is being directed towards the investigation of new filter configurations exhibiting better electrical performances. In this sense of paramount relevance is the filter's selectivity which must always be increased in order to better reject the spurious signals escorting the useful information, a key issue for many satellite communication applications.

In this contribution, we investigate several filter configurations including broadside coupled microstripline sections and explore the possibilities of implementing transmission zeros in the insertion loss response. For this purpose we have first developed a fast and accurate software tool for the rigorous analysis of the structures being investigated. Using the developed software tool, two techniques for the implementation of transmission zeros have been examined. In the first technique we take advantage of the broadside configuration to introduce cross-coupling between non-adjacent resonators. With this technique, a single transmission zero can be placed to increase the selectivity of the filter above the pass-band and the position of the zero is easily modified by controlling the strength or amount of cross-coupling. Furthermore, another transmission zero can be implemented below the pass-band by using the interaction between the higher order modes excited in the air-dielectric interfaces of the substrates used to print the line resonators.By controlling the amount of coupling going to the excited higher order modes, the position of the transmission zero can be modified accordingly. A way to do this is to vary the distance from the last air-dielectric interface to the metallic top cover of the filter. An alternative way is to open a slot into the top cover. It is shown that the position of the transmission zero is effectively controlled by the position of the slot. Finally, by combining both techniques, two transmission zeros can be placed to increase the selectivity of the filter on both sides of the pass-band.

In the Figure we present two filter examples optimized with our software. More results and measurements will be presented in the conference for real practical filters. Results confirm the effectiveness of the techniques to place transmission zeros on the insertion loss response of microwave filters and thus increase selectivity.



Multilayered Substrates to design high performance wideband couplers and filters

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Microstrip passive components such as couplers, band pass filters or phase shifters generally use sections of coupled lines. Performances of such devices closely depend on the phase velocity difference observed between the normal modes in each section of coupled lines.
For narrow-bandwidth devices, compensations can be easily implemented in the circuit design in order to prevent the degradation of performances. This can be achieved, for instance by CMS or integrated capacitors, modification of the inner geometry of the lines, etc.... It is more difficult to compensate parasitic effects for wideband devices.

As shown in figure 1, for two coupled lines, the field configurations of the even and the odd mode are relatively different :

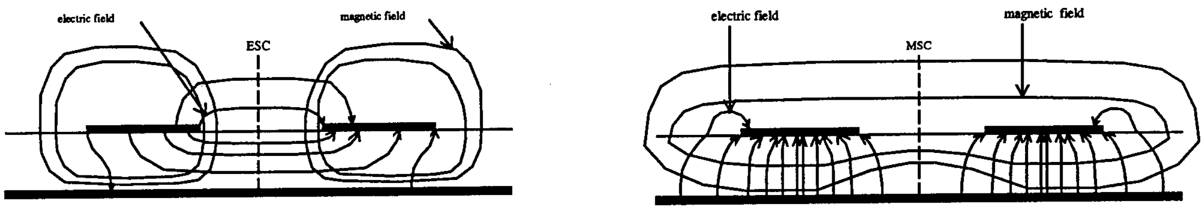


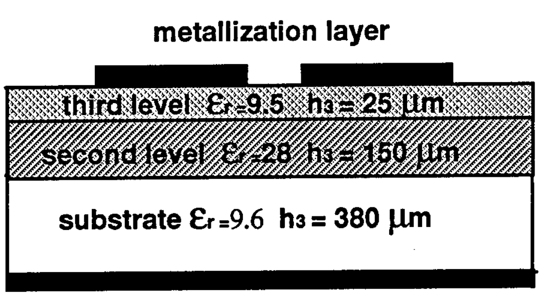
Fig . 1 The normal modes for coupled microstrip lines

- For the even mode, the electric field is mainly vertically polarized and the related energy is concentrated under each strip.
- For the odd mode, the energy is concentrated close to the surface of the substrate between the two strips and the electric field is mainly horizontally polarized.

It is expected that it is possible to modify the phase velocity of each mode by locally modifying the nature of the substrate to obtain a ratio R close to 1. (see figure 2)

In this way, we propose to develop multilayered substrates in order to compensate the difference between the phase velocity of the normal modes in each coupled section. An exact compensation can be theoritically obtained on a large range of coupling factor. ($0.01 < k < 0.5$). As a result, it is possible to design wideband passive devices using such a technique.

In order to build multi-layered substrates, we use thick film technology and dielectric inks.
The values of the available permittivity range from 4 to 28. Also, the height of each deposited layer depends of the technological process. Consequently, it is relatively difficult to obtain an exact compensation. However , as presented in figure 2, a very good approximation can be obtained with a three layer substrate.



CdB	6	8	10	14	20
R	1.01	1.01	1.00	0.98	0.96

with $R = \varepsilon_{reffo} / \varepsilon_{reffe}$

Figure 2: A three layer quasi-optimal substrate to build compensated couplers.

Couplers and filters that were built on such substrates showed the following improvements:

- Couplers : a growth of the directivity
- Filters : a better mastering of the spurious responses out of the bandwidth.
- Easy compensation techniques to build wideband devices.

This work has been supported by Alcatel Telecom-Toulouse-France

A New Design Method for the Realization of the LC Low-Pass Filters Using Microstrip Lines

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At frequency much above several hundred MHz,lumped componenets tend to become physically small and therefore difficult to handle.Beside this,as frequency is increased the lumped components depart from their ideal characteristics due to radiation and loss mechanisms present within the devices.At frequencies high enough to make distributed lines attractive then sections of transmission line are used,whose length and characteristic impedance can be carefully selected to simulate the behaviour of a LC ladder type filter.

A loseless waveguide with electrical length-q and characteristic impedance-Z_C ,can be defined as a T or P equivalent circuits whose serial and parallel components are inductances and capacitances respectively.With the consideration that q=b.l << 1 and tan(b.l) @ sin(b.l) @ b.l, the two-port circuit terminated with normalized R_L resistance,behavious like serial inductance ($L=Z_C$.l/u) or like parallel capacitance ($C=Y_C$.l/u) for $R_L << Z_C$ and $R_L >> Z_C$ respectively.

In the literature,authors first calculated the L,C values upon to the requirements and then obtained the paremeters necessary for designing the microstrip lines.

In this work,the Bernstein polynomial,B_n(f:x) ,which is given below,is used to obtain the standart L,C low-pass filter amplitude response [1] ;

$$B_n(f:x) = \sum_{k=0}^{n} f(\frac{k}{n}).\binom{n}{k}x^k.(1-x)^{n-k}.$$

From the equivalence between the amplitude responses the L,C=R(f_k ,n) functions are obtained.It will be shown that all types of filters and ones didn't realize since today can be obtained as special cases from an unified analytical procedure by changing only the f_k-parameters in the Bernstein polynomial.With this occasion,designers will be able to observe the slopes at the cut-off frequency and also point out the maximum and minimum positions in the pass band at the same time without geting the results of the calculation of the L,C values and corresponding figures.Also it will be shown that a more general filter would be obtained, giving a better compromise in amplitude and phase responses since none of the ones designed before gives good results in this two respects.

In the conference,the analytical functions will be given with the lots of examples including the effects occured both from the microstrip layer thickness and the changes in width, where with this occasion the unique of the method will be seen clearly.

Reference

[1] P.J.Davis "Interpolation and Approximation" Ginn-Blaisdell,Chapter 6,pp.108,1963.

A New Low-Pass Filter Design Based on the Required Phase Response

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In the litereature,the amplitude response function of the filters are discussed basicly and the authors accepted the phase responses born by these amplitude response functions.With the increasing importance of the phase responses,authors are attentioned on both the amplitude and phase responses of the filters.But since today,the derived methods didn't give good results in both respects.Lately,only the new design method derived for the amplitude responses [1] gave the good results.

In this work,the mentioned new design method,which uses Bernstein polynomial,will be applied to the phase response function to obtain good results in both respects and it will be shown that all phase response types and the rest unrealized ones can be obtained as special cases from a unified analytical procedure by changing the Bernstein polynomial.The Bernstein polynomial is defined as follows [2]

$$B_n(f\!:\!w) = \frac{1}{2^n}.\sum_{k=0}^{n} f_k.\binom{n}{k}(1-w)^k.(1+w)^{n-k}$$

For the unification of the ladder type L,C filters with a resistive termination,a low-pass filter (LPF) design is considered as a basic unit.So that we will be able to make comparison with the previous ones easily.

The amplitude characteristic of a LPF with no finite zero can be expressed in the following form ; $A(w) = 1/\sqrt{1+f(w^2)}$ where $A(w) = |H(jw)|^2$ and $H(jw) = |H(jw)|.e^{j\Phi}$. Here, $f(w^2)$ is a positive real function of w^2 and is realized by using the $B_n(f\!:\!w)$.If we define the H(jw) function as, $H(jw) = 1/\left[r(w) + j.s(w)\right]$,where r(w) and s(w) are even and odd functions of w respectively, the phase response function will be , $\Phi = \mathrm{Arg}\left[H(jw)\right] = -\arctan\left[\frac{s(w)}{r(w)}\right]$. By applying the new method,the new phase response function can be given as $\Phi(f_k, n, w) = -\arctan\left[\frac{\overline{s}(f_k, n, w)}{\overline{r}(f_k, n, w)}\right]$.

It will be seen that this new method will give us a posibility to control and change the values of the phase response function at a given w- point.Again,designer will be able to set the phase responses for w >1 and by the time will be able to change the values in the pass-band.The analytical phase response function will be given in the conference with the examples comparing the phase responses between the new ones and the well-known LPF.Also,it will be shown that,designers will be able to make an arrangements between the amplitude and phase responses as they are required.

References

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20GHz Tunable Filter Based on Ferroelectric Films

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The interest in the application of ferroelectric, in particular $(Ba,Sr)TiO_3$ (BSTO) films, at microwave frequencies for the creation of tunable devices (filters, phase-shifters) is determined by following features of these materials: the high speed of the dielectric constant variation under electric field, the high level of microwave power corresponding to the irreversible destruction of ferroelectric film elements, high resistance to x-ray, neutron and other types of irradiation, low controlling consumption energy and low cost of manufacture of ferroelectric elements.

However there are limited information about dielectric properties (dielectric constant and dielectric losses) of BSTO films at frequencies over 20 GHz. Present paper is devoted to the measurements of characteristics of ferroelectric varactors at ~ 20 GHz and ~ 30 GHz and to design the tunable filter for frequency ~ 20 Ghz.

Planar varactors based on $(Ba_{0.4},Sr_{0.6}TiO_3)$ ceramic films (thickness ~ 4 mm) deposited on the polycrystalline MgO substrates were used for the microwave measurements and for the filter designed. Capacitance of the varactors was 0.4 pF. Under bias voltage U = 400V the capacitance of varactors is decreased in 2.5 times. Microwave dielectric loss (tand) was decreased from 0.1 to 0.05 under bias voltage.

The two-pole 20 GHz tunable filter employing BSTO capacitors is based on the finline in a rectangular waveguide. The fin construction comprises three metal copper plates (thickness is 0.2mm) placed at the center of waveguide along its longitudinal axis. Two lateral plates with slot line resonators are grounded due to the contact with waveguid. Central plate is insulated from waveguide by mica and is intended for the control voltage application to varactors. Two ferroelectric varactors are included in the every slot line resonators.

In the frequency range of the tuning DF≈1.2GHz (~6%), the filter demonstrates the insertion losses L_0 not more than 3.8dB and the bandwidth Df/f ≅ 3.5% at the level of the transmission coefficient $L_s = L_0 + 3dB$ = 6.8dB. The reflection coefficient was S11≤ -20dB for the any point of the tuning range. The experimental data are in agreement with theoretical estimation calculated in accordance with [1].

References.

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Analysis of a Grating-Assisted Directional Coupler Using Coupled-Mode Formulation Based on Singular Perturbation Technique

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Grating-assisted directional couplers are promising devices for optical waveguide filters. Complete power transfer between two coupled waveguide is possible only when they are synchronous. The coupler consists of two asynchronous waveguides and the synchronism can be achieved by a attached periodic grating structure on either waveguide. The two coupled-modes in the system are phase-matched through the space harmonic components generated by the grating, and complete power transfer from one waaveguide to the other occurs at a certain wavelength satisfying Bragg condition. This leads to a wavelength selective coupling in a two-waveguide coupler.

The power transfer characteristics in grating-assisted directional couplers have been investigated using the improved coupled-mode theory. Grating-assisted directional couplers utilize the second-order perturbations when the effects of the adjacent waveguide and grating are supposed to be first-order perturbations. However, the total wave fields in this formulation are expressed as a linear combination of the modal fields of the individual waveguides in isolation, and therefore this formulation is correct up to first-order. Accordingly, the improved coupled-mode theory may not always have sufficient accuracy to analyze grating-assisted directional couplers.

In this study, we analyze a grating-assisted directional coupler by using the coupled-mode theory based on singular perturbation technique[1]. This formulation includes higher-order corrections of the perturbed modal fields and enables us to evaluate effects of higher-order perturbations rather than the first-order ones. We calculate up to second-order problem and obtain coupled-mode equations which give the Bragg condition correct in second-order.

Reference

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Analysis of a Three Line Microstrip Coupler on Anisotropic Substrate Using Closed Form Expressions

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A three line microstrip coupler is used as a refectometer in modern network analysers. The main advantage of these couplers on anisotropic substrates is the improvement in isolation and directivity through very close equalization of the even- and odd-mod phase velocities and still maintaining the fabrication simplicity through photolithography. The quasi-static characteristics of these couplers can be obtained from the capacitance matrix of the structure and using the equivalent substrate thickness and equivalent dielectric constant to account for the anisotropy effect. Most of the methods developed for this purpose generally involve time consuming numerical procedures. In thise paper semi-empirical design equations for symmetrical three line microstrip couplers (TMC) on anisotropic substrates have been developed. In this method the total capacitance of the system is divided into strip capacitance, fringe capacitance and gap capacitance, which are easily calculated by empirical and semi-numerical relations. From these capacitance values, various mode impedances and coupling coefficients of the microstrip coupler are obtained. However for a practical coupler the effect of the enclosure is to be considered. For this purpose the critical shielding height is to be determined. Numerical results for A-, B-, and C-mode impedances, various capacitances and critical shielding heights for various dielectric materials have been obtained.

Session H02
Tuesday, July 14, AM 08:40-12:20
Room R02
Composite Material Modeling I
Workshop on Complex Media and Measurement Techniques

Organiser : C. Brosseau

Chairs : C. Brosseau, U. Federhof

Faraday Effect in Composites

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We study here the Faraday effect in a binary composite. Since the Faraday effect is very weak in dielectrics, we study a mixture made of a dielectric matrix with metallic inclusions. We will study the quasi static limit and therefore, the composite medium can be described by an effective permittivity tensor. Determining the effective medium properties of disordered materials is a difficult problem and one has often to resort to perturbative methods (low field, low density or low contrast) which cannot be applied for high magnetic field for instance. In contrast to the Hall effect, the Faraday effect in metal-dielectric composites was until now only discussed using a Clausius-Mossotti-type approximation, which is good for dilute systems, and a Bruggeman-type self consistent effective medium approximation, which exhibits a percolation threshold but with incorrect values of the critical exponents. In the present study we employ two different approaches which are not limited to dilute systems, and one (the high contrast expansion together with scaling ansatzes) is expected to lead to reliable results for the critical behavior near p_c. The first method is based on the use of the replica method together with a variational principle. This treatment possesses the advantage that it is non-perturbative and may thus be useful for strong disorder or strong fields. Moreover it has been shown that it can give reasonable values for the permittivity tensor if the system is not too close to the percolation threshold. However, the critical exponents are not reproduced correctly (one usually gets mean-field or effective medium approximation (EMA) exponents). In order to present an alternative discussion of this problem, and obtain the correct exponents near the percolation threshold, we introduce a high contrast expansion. This is essentially an expansion in powers of the ratio of resistivities or permittivities of the two components, which can be made very small by making the frequency of the incoming wave very small. This expansion can be used for weak magnetic fields as well as for strong magnetic fields. In order to discuss the critical properties near p_c, we apply some scaling ansatzes to that expansion, which are based upon previous discussions of d.c. magneto-transport. Our conclusions are the following. First of all, both approaches are consistent with each other, the only difference is that the scaling exponents predicted by the replica approach have their effective-medium values. Second, the main result is the following: the scaling of the Faraday coefficient is the same for the weak field and the strong field regimes. In particular, the two methods predict that near the percolation threshold (and below, that is, in the dielectric region), the Faraday effect is greatly enhanced. Indeed, we predict that it should be in principle possible to obtain large values of the rotation angle in such a system (the Faraday coefficient could be made of order unity using currently available magnetic fields and high mobility doped semiconductors). Both approaches also predict that the transverse diagonal elements of the effective permittivity tensor have a non-zero imaginary part which means that there will be some dissipation.

New Aspects of the Dynamic Behavior of Partly Magnetized Composite Materials

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The use of magnetized ferrimagnetic substrates (ferrites) in electronic circuits allows the implementation of microwave signal processing functions (phase shifter, attenuator, insulator, circulator,..). The exploited physical properties are a very low electrical conductivity enabling a strong interaction of the electromagnetic wave with the matter and either a nonreciprocity due to the gyrotropic effect neither the possibility to change the electromagnetic characteristics as a function of magnetic commands.

The physical and technological limits of ferrites for applications in higher frequencies led us to study substitute materials. A solution consists in mixing various components in order to get a medium with the properties wanted. The composite material considered is made of ferrimagnetic or ferromagnetic inclusions embedded in an insulating matrix which warrants the electric insulation of the bulk material in the case of conducting inclusions.

Conceiving as well as practical achievement of microwave devices using such materials needs on one hand the theoretical study of their dynamic behavior and on the other hand frequency measurements of their electromagnetic characteristics (permeability tensor components of the bulk material).

A first step to study heterogeneous magnetic materials has consisted in working out a dynamic model for the tensorial permeability of magnetic inclusions taking the multidomain nature of the magnetic particles into account. This statistical model is different from the previous ones in the way it does not consider the matter partly magnetized as a set of independent domains but as a set of independent grains composed of interactive domains. The comparison between the elements of the tensor and measurements performed on a resonant cavity on bulk ferrites or with models existing in their validity domain is very satisfying. The macroscopic response of the disordered medium is then obtained from an effective medium theory (E.M.T.) exploiting the tensorial permeability issued from the model previously described. We have already validated this theory for heterogeneous isotropic materials in microwave. Its validation in the anisotropic case (i.e. under static magnetic field) requires a comparison with experimental results. In this prospect we have worked out a broad band characterization method for measuring the complex permeability tensor components of magnetized materials. The technique is based on the reflection/transmission measurement of a rectangular waveguide partly filled with the material to be characterized. The fundamental principle of the measurement consists in using the anisotropy of the material to lead to the nonreciprocity of the device in order to have the same number of measurable parameters (the S parameters of the cell) as for the characteristics we want to determine.

We shall present the theory developed to describe the dynamic behavior of magnetized composite materials that consists in using a new tensorial permeability model with an E.M.T.. Then we shall describe the measurement cell that enables us to compare the theoretical results with experimental data.

Dielectric Constant of Lossy Composite Materials

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Because of numerous practical applications of the composite materials which can be intended in different areas (electronics, telecommunications and aerospace industries), extensive investigations have been undertaken during the last decades, in order to characterize these heterostructures. The study of dielectric properties of these materials constitutes one of the main subjects of these investigations.
In spite of the sustained efforts, the search of new materials having specific physical properties has been mainly empirical, because no exact theory is currently known that relates macroscopic properties of multiphase composites to their microscopic properties. In recent works, we shown that the use of numerical methods (Boundary Integral Equation-BEM- method and Finite Element method-FEM) enables to evaluate the complex effective permittivity of lossy composite materials with a good accuracy.

The purpose of this paper is to present and discuss the results of a computer-simulation model that is based on the resolution of the finite element (FEM) with careful attention paid to the numerical evaluation of the effective permittivity, in the quasistatic limits.
The complex values of the permittivity of two-component lossy heterostructues, composed of inclusions of permittivity e_1 embedded in a host matrix of permittivity e_2, are rigorously evaluated with use of the finite element method and the code FLUX3D. Different three-dimensional topological arrangements of the components are considered. This concerns especially spherical and discoidal inclusions, of finite conductivity, periodically arranged in three-dimensional lattice structures (simple cubic, body-centered cubic, face-centered cubic and diamond). The percolation threshold volume concentration is analyzed depending on the type of lattice. The computational results are compared to those reported previously in literature. It is shown that the dielectric properties of two-component lossy heterostructues strongly depend on the internal structure of the medium i.e. the shape, the volume fractions and the arrangement of the different components. The critical exponents which determine how the real and imaginary permittivity scale with the distance from the percolation threshold were determined for the simple cubic lattice and are consistent with the scaling predictions of percolation theory for infinite three-dimensional lattices of insulator-conductor mixtures.
The effect of anisotropy is also studied for discs with various radius-to-length ratios. Increasing the radius-to-length of one order of magnitude shifts the percolation threshold by more than two decades.

Broadband Dielectric Spectroscopy as a Method to Characterize the Microstructure of Composite Materials

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The permittivity of a composite material strongly depends on its microstructure, e. g., on the spatial distribution of conducting particles dispersed in a host matrix. Often this information is not not available and thus a comparison of experimental data with theoretical models is difficult. Particles in contact may nevertheless be separated by unknonwn contact resistances. On the other hand, even if particles are separated by a thin insulating layer, a charge transport via hopping may be possible. An analysis which does not take into account the strong frequency dependence of the permittivity rarely allows an insight into the microstructure. On the contrary, temperature dependent broadband dielectric spectroscopy is sensitive with respect to the topology and, e. g., allows to monitor agglomeration effects. Polarization processes and transport mechanism can be studied. Both the interfacial polarization of the particles and the conduction current relaxation define the range, in which $\varepsilon(\nu)$ exhibits a strong disperion characterizing the topology of the system. We present data in a large temperature and frequency range (dc - 2 GHz, 100 K - 350 K) showing how to characterize the microstructure and to determine unknown particle conductivities or sizes.

Dielectric Constant and Van der Waals Binding Energy of Disordered Polarizable Systems

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The dielectric constant and van der Waals binding energy of a disordered polarizable system are determined by the average local field acting on a selected particle. The microscopic structure of the system is reflected in the absorption spectrum and density of states. Even the low density limit is nontrivial. It is characterized by a universal lineshape, which can be calculated only approximately. At higher density correlation corrections must be taken into account. An approximate self-consistent theory leads to fairly good agreement with computer simulation data.

Dyadic Green's Functions for Multilayered Isotropic Media

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This paper presents a systematic and unified formulation of the dyadic Green's functions for arbitrary multilayered isotropic media. The media are stratified in a general direction which includes the canonical cases of planar, cylindrical and spherical geometries. The total number of layers can be arbitrary, so are the field and source locations. Within each layer, the medium is homogeneous with its permittivity and permeability assumed to be different from other layers. Based on the principle of scattering superposition, both electric and magnetic dyadic Green's functions are derived simultaneously in terms of unbounded and scattered parts. For the unbounded dyadic Green's functions, their complete eigenfunction expansions are expressed in terms of propagating solenoidal vector wave functions. For the scattered dyadic Green's functions, their scattering coefficients are determined using the effective plane wave reflection and transmission concepts which make use of the global (or generalized) matrices that incorporate the effects of multiple-reflections. This approach has avoided cumbersome operations and has also provided good physical insights to the scattering mechanism. Throughout the formulation, all matrices to be dealt with are of order 2 by 2 only. The resulting general expressions are written in very compact and convenient forms using the Kronecker delta symbol and the Heaviside unit step functions. To demonstrate the application of these expressions, the three canonical cases of multilayered isotropic media are considered explicitly. For each of these cases, it is noted that only a unique matrix associated with the particular geometry needs to be determined, then all other matrices can be calculated readily using this matrix in a set of unified formulas. For illustration, some specific examples of two and three-layered media are discussed in particular. As a final note, the general formulation described here can be extended readily to treat more complex problems such as chiral, biisotropic and bianisotropic multilayered media.

Modeling of Interaction Electromagnetic Waves with Random Active Media

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1. Introduction

Necessity of the decision of real problems on propagation and scattering of signals in nonstationary active random media : turbulent flows of a liquids, gases, plasma and ensembles of oscillators requires creation of new methods of the decision.

The purpose of this work is development of a numerical method of calculation propagation and scattering of electromagnetic waves in nonstationary active random media.

2. Method of calculation

The wave falling on the random active media is modeled by synchronouse phase coherent rayes, which are distributed uniform in plane wave front and are orientated along direction in propagation wave.

The length of free propagation of ray in inhomogeneous random active media is determined in accordance to probability of absorption, scattering and fictitious scattering. The direction propagation of ray in case execution condition scattering wave is changed in according to indicatrix of over-radiators (V.G. Spitsyn, Electromagnetic Waves and Electronic Systems, 2, 45-49, 1997). Every act interaction of signal with oscillator is accompanied by displacement the frequency of signal and of oscillators vibrations.

3. Results of calculations propagation waves in turbulent flows

We consider multiple scattering of electromagnetic waves on the strong fluctuation dielectric penetration the flow of plasma. The numerical model of multiple scattering waves in turbulent flows of plasma is proposed. We consider propagation wave through flow with inhomogeneous profiles velocity and concentration of turbulences.

Sounding turbulent flow of plasma along him axis is considered. In this case scattering of electromagnetic wave on the inside surface body of rotation: cone and paraboloid second and four orders takes place. The calculation of angle and frequency spectrums of scattering signal is conducted.

The comparison of the form of experimental frequency spectrum, received for the case of sound following the turbulent flow of plasma along its axis (J.S. Draper, P.O. Jarvinen, and T.D. Conley, AIAA Journal, 8, 1568-1573, 1970) and frequency spectrum, received in the result of numerical modeling in our work, is spent.

4. Interaction of electromagnetic signals with system of oscillators

The model is suggested, which describe transfer of signals in three dimensional system of oscillators with stochastic connections. The process of interaction of signals with oscillators, chaotic disposed in spherical region is investigated.

Influence of the harmonic signal on the system of oscillators with disperse of frequency oscillators' vibrations is leaded to decreasing of the width of frequency spectrum of oscillators' vibrations and to normalization its form.

5. Conclusion

In this work a method of modeling propagation electromagnetic waves in nonstationary active random media has been offered. A problem about propagation of a wave through a flow with inhomogeneous of a structure of velocity and concentration of turbulences has been solved. The comparison of results of accounts with experimental data on electromagnetic sounding of a flow of plasma has been spent. It has been shown their satisfactory conformity. The process of interaction of electromagnetic signals with ensembles of oscillators has been investigated.

The result of interaction of the harmonic signal with the system of oscillators shows that decreasing of the width of frequency spectrum of oscillators' vibrations andmonochromatization its form takes place.

Fundamental Limitation for Thickness to Bandwidth Ratio of Radar Absorbers

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Methods for designing broadband thin radar absorbers have been of interest for a long time. Conventional approach to the problem involves numerical optimization of characteristics of the absorber on the base of some appropriate law for frequency dependence of permittivity and permeability. This approach produces only particular solution for the problem and is useless in searching whether this solution may be made better and in what extent.

We consider frequency dependence of reflection coefficient R of a one-layer magnetodielectric absorber with arbitrary frequency dispersion of permittivity and permeability. Analysis of its properties based on Cauchy theorem results in fundamental inequality

$$\left| \int_0^\infty \ln R \, d\lambda \right| \le 2\pi^2 \mu_0 d \tag{1}$$

where λ — wavelength, d — thickness of the layer, μ_0 — its static permeability.

The inequality (1) is useful in estimation of the broadest possible operating bandwidth that can be achieved with radar absorber of given thickness d. It follows from (1) that the thickness to waveband ratio is restricted as follows:

$$\frac{\Delta\lambda}{d} < \frac{2\pi^2 \mu_0}{\ln R_0} \tag{2}$$

where $\Delta\lambda$ is the bandwidth, and R_0 is the largest value of reflection coefficient within the operating waveband. For broadband, purely dielectric absorbers ($\mu_0 = 1$), inequality (2) leads to conclusion that it is impossible to produce an absorber providing 10 dB reflectivity level and thickness that is less than 1/17 of the largest operating wavelength.

When narrow-band absorbers are under consideration, inequality (2) produces inaccurate estimate for the least value $d/\Delta\lambda$. In this case, all the absorption in the material could not be located within narrow waveband $\Delta\lambda$, and more realistic estimate is

$$\frac{\Delta\lambda}{d} < \frac{16\mu}{\ln R_0} \tag{3}$$

where μ is the real part of permeability at operating frequencies. Comparing the above inequality to well-known estimate for bandwidth of thin absorber with frequency-independent values of permittivity and permeability one can readily deduce that proper choice of dielectric dispersion can result in 4.5-fold increase of operational waveband of a 10 dB absorber.

The results are confirmed by examples of numerical optimization of radar absorbers. The approach can be readily extended to the case of multi-layer absorbers.

Electromagnetic field interaction with a half-space with continuously time-varying conductivity

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Electromagnetic field transformation in transient media was studied in detail for the case of abrupt change of media properties. As it is known from the exact solutions and experiments, the main result of such a temporal discontinuity is the splitting of the source (incident) wave into new waves: the direct one (moving in the same direction as the incident wave) and the inverse one (moving in the opposite direction) whose frequencies are different.

In the case of continuously time-varying media parameters the problem becomes much more complicated. Some of its approximate solutions were obtained for a few special cases of the properties time-dependencies. Its numerical solution also meet great difficulties such as a rapid growing of calculation error with each step of the procedure. Besides, such solutions could not reveal all features of electromagnetic field behavior in the time-varying media.

The topic of this paper is the exact analytical solution of the problem for the electromagnetic field transformation in a case when transient medium is a half-space with continuously time-varying conductivity. One-space dimensional problem is considered in assumption that the field has only the component normal to the propagation direction.

The initial point in solving of this problem is the Volterra integral equation for the internal transformed field (field inside the transient region). As outside this region the medium is assumed to be simply a stationary homogeneous one, it seems that it is more easy to begin the solution of the problem from the stationary half-space. After reducing the integral equation for the internal field to the partial differential one for this field in a shifted time moments one has managed to obtain from it the ordinary differential equation for the external field. This equation could be solved exactly for some cases of the conductivity time-dependencies which could be realized in practice such as a splash-like one and some others. The obtained exact solutions for the fields are analyzed theoretically and numerically.

Effective dielectric and magnetic properties of planar metal-dielectric films

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The interaction of em wave with thin semicontinuous metal film is considered. The size of metal grains sputtered over a dielectric substrate is assumed much smaller than the wavelength of the incident wave. It is shown that the film absorbs em energy effectively even if the absorption in metal grains and a dielectric substrate is negligible. We propose that the effective absorption results from localization of the em waves in the film. The localized field has form of picks of the local electric and magnetic fields distributed over the film. The amplitude of the field peaks may exceed the amplitude of the incident wave by many orders of magnitude while distances between them are much larger than the metal grain sizes. The knowledge of the field distribution allows one to choose such film parameters that increase the absorption and decrease reflectance significantly in certain frequency range.

J. I. P. R. 4 - Session I02
Tuesday, July 14, AM 08:40-12:20
Room 200
Basic Polarimetric Concepts and Applications
Organiser : Y. Yamaguchi
Chairs : Y. Yamaguchi and D.L. Schuler

Comparison of Various POL-RAD and POL-SAR Image Feature Sorting and Classification Algorithms

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Classification and identification of radar targets make up some of the most important applications of modern, fully polarimetric high-resolution radar systems. The availability of fully polarimetric data in multiple frequency bands makes it possible to extract a vast amount of target characteristic information, which is well suited for automatic classification procedures. However, the information can be represented in numerous ways, e.g., relying on mathematical, statistical, and physical properties. Proper selection of target features is therefore of importance for optimizing the use of such data.

The concept of polarimetric decomposition plays an important role in this context, especially because of the possibility of thereby obtaining unique, basis independent target descriptors, unlike directly measured data which usually contain some degree of arbitrariness, associated with the given measurement basis. For example, the scattering matrix elements in a linear basis are highly sensitive to relative orientation between target and radar, while a characterization of the target properties should preferably not depend on target orientation. Another advantage of certain decomposition techniques is that amplitude information is combined with phase information so as to provide a description more closely related to physical scattering mechanisms and other target properties.

Some different representations and decompositions of polarimetric data and their relations to physically relevant target characteristics will be reviewed in this paper, and several examples of high resolution imagery will be shown, based on L- and C-band data from the Danish EMISAR system.

Resolution Enhancement of the MUSIC Algorithm with Wave Polarization

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The scattering center detection of radar targets is a basic problem for the radar imaging. Direction of arrival and time-delay of local scattered waves can be estimated by receiving antenna array with CW radar such as step-frequency and FM-CW radars. In addition, when we obtain full polarimetric data, we can estimate the local shape of each scattering center. However, dominant local waves must be discriminated to obtain the true polarimetric parameters corresponding to the shape. Therefore, high-resolution imaging radar is required.

In this paper, we propose an efficient MUSIC algorithm for direction and delay time estimation of radar target imaging utilizing full polarimetric data. The MUSIC algorithm is one of the superresolution technique, and has a superior resolution performance to the conventional Fourier technique. The application of the MUSIC algorithm to the active radars, decorrelation of the local scattering signals is an important problem to realize a high resolution performance. We propose polarization averaging preprocessing technique for the method in addition to the conventional so-called spatial smoothing preprocessing scheme. The method has two main advantages compared with the conventional one. First, decorrelation performance is improved. Second, the number of resolvable local waves is increased. The resolution improvement is verified theoretically and experimentally.

The polarization parameters of each local scattered wave can be easily calculated using the estimated scattering center location. These parameters can be available for the polarimetric imaging processing such as the polarimetric filtering, three-component decomposition, and so forth. Using the estimated locations of the scattering centers with their polarization parameters, we can easily obtain polarization images of the target, that are available for target classification.

Scattering Matrix of Line Targets Aligned in the Range Direction

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The Sinclair scattering matrix is defined in a fixed radar range. If the radar target extends in the range direction within a radar beam, the reflected signal or the resultant scattering matrix will undergo interaction of multiple reflections in the range direction. In this paper, two basic wire targets aligned in the range direction is investigated with respect to the final scattering matrix. The purpose is to examine the effect of orthogonal and non-orthogonal wires placed in the range direction. First, the well-known FD-TD method is employed to analyze the scattering phenomena due to the spacing between two targets. The time-domain signal is inverted into frequency domain where the single frequency behavior is apparent. It is shown that the final scattering matrix becomes the simple form for this case. The nearest scattering matrix appears the first and then the second scattering matrix comes, multiplied with the phase difference due to the spacing. This characteristic ap ! pears periodically. This fact shows that the two wires could become sphere and helix component generator. This phenomenon is also verified with a laboratory measurement using a network analyzer. This fact shows that the target decomposition should be carefully carried out in terms of range. If the range resolution of a radar is finer than a desired target dimension, the forefront scattering matrix is affected by the scattering matrices by the next range cell.

Optimal Polarimetric Contrast Enhancement in Partially Polarized Scattering

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In radar target identification, discrimination, and imaging, it is desirable to enhance a polarimetric contrast between two classes of scatterers or scatterer ensembles by selecting the polarization states of transmitting and receiving antennas. Several optimization procedures for the completely and the partially polarized cases have been proposed based on the theory of radar polarimetry.

The purpose of this paper is to investigate optimization of polarimetric contrast between two time-varying targets using a covariance matrix formulation. Suppose that the time-dependent targets with known polarization characteristics are illuminated by a plane monochromatic wave. Then the scattered waves can be considered partially polarized. As is well known, mean powers carried by the co- and cross-polarized backscattered waves in any orthogonal polarization basis AB are determined by the main diagonal elements of the covariance matrix. The ratios of mean power returns in the two orthogonally polarized radar channels A and B are optimized as a function of transmitter polarization. Numerical examples are presented to give the optimal transmitted Stokes vectors in the co-polar and cross-polar radar channels.

In the analysis, the time-averaged covariance matrices for the two targets in the linear polarization basis HV are assumed to be known *a priori* by measurements. The covariance matrices in the basis AB can be readily obtained by using a unitary basis transformation matrix. Note that the optimization procedure discussed here may also be applied to the time-invariant and deterministic targets.

Estimation of Radar Objects Contrast with Using the Group of Huynen-Euler Invariant Polarization Parameters

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The general feature of surveillance radars is that all of them, without exception, form a "man-machine" information system. Its operation includes the following stages :

1. Generating of primary radar information about observable surface (environment); it is based on measurements of the scattered signals parameters and estimation of characteristics of the objects of interest ;
2. Imaging of the information in the form that is accessible and convenient for operator perception ;
3. Analysis of the periodically updated information by the operator and his making of decisions which allow the given task to be performed.

The basic function of the "man-machine" information system consists in obtaining and imaging of radar data in the form , which maximally facilitates the selection process of man-made (or natural) targets of interest against surface- or volume-distributed background. Thus, all three stages are directly connected with the targets observability concept. The observability degree depends on a lot of objective and subjective factors. In the general case, the targets observability is an integrated result of objectively existing radar contrast (being found out by surveillance radar functioning), color-brightness contrast of the radar image and features of subjective perception of operator. The measurable difference in backscattering properties constitutes the objective basis for selecting (by operator) the specific target among other objects of observation. Polarization contrast (PC) value is a quantitative estimation (measure) of this difference. It was Prof. Kozlov A.I. who first formulated the given concept with respect to problem of radar surveillance [1]. Some of the PC features concerning one of the scattering matrix invariants - degree of polarization anisotropy, were investigated by the author in [2].

The concept of objective polarization contrast of two objects is a special case of the radar contrast. Nevertheless, it is a rather productive one for solution of stationary and moving targets selection problem. From the point of view of real measurements, the most interest is to answer a question, what polarization parameter (or parameters group) of the scattering matrix must be measured to achieve the maximum distance between points in the polarization signatures space, which correspond to the objects compared.

In the given paper, results of the PC concept development are considered in connection with analysis of the normalized polarization contrast between "simple" ("O1") and "compound" objects ("O1+O2"), with the use of Huynen-Euler invariant parameters group [3]. It is analyzed in what extent the changes of parameters, corresponding to the objects "O1" and "O2" separately, influence the Huynen-Euler parameters of the compound object, and, hence, polarization contrast between "O1" and "O1+O2". Numerical estimations of the polarization contrast between the objects above for every Huynen-Euler parameters are given : maximum polarization, absolute phase, orientation angle, helicity angle, skip angle and characteristic angle. The results of calculations are presented as 3-D graphics. Since the quantitative estimation (or measure) of the polarization properties difference can be given by different ways, in the paper various approaches to estimate the PC are compared for the case when the parameters change in the given intervals. The data obtained (for example, histograms of PC values of the objects analyzed) allow to evaluate the Huynen-Euler parameters compare between themselves, from the point of view of ensuring the maximally possible distance between corresponding points in the polarization signatures space.

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Polarimetric Radar Receivers Canceling the Partially Polarized Clutter

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Complete cancellation of radar clutter is a competitive method to that ensuring maximum contrast of the target under observation against the disturbing background. Realization of the complete radar clutter cancellation requires employing two receiving channels: one with signal plus clutter, and the other with clutter only. Moreover, the clutter vectors in the two channels should be identical. The next step is to build up the receiving vector orthogonal to the clutter. Such a receiving vector when multiplied by the vector of signal and clutter, received in the first channel, will produce the unperturbed received signal.

Coherent optimum receiver completely canceling the partially polarized clutter produces a completely polarized receiving vector orthogonal to the instantaneous Jones vector of clutter. The coherent receiver can be optimal, because the Jones vectors' space is two-dimensional, and only one vector orthogonal to the clutter exists. Such receiver has been proposed, e.g., by Qiao and Liu [1]. They separated the channels in video frequency. Unfortunately, it is not always possible to select the channel with clutter only in a coherent receiver, especially when clutter should be polarimetrically identical as in the channel with the perturbed signal. Then the noncoherent receiver should be applied employing the receiving four-vector perpendicular to the Stokes four-vector of clutter. However, in the four-vector space more vectors can be perpendicular to the clutter. There exists the three-dimensional subspace perpendicular to any four-vector if only the condition of physical realizability, usually applied to Stokes four-vectors, will be ignored. Such condition can be neglected because there is always possible to build up the receiving four-vector with its first component of any value, even negative one. Maybe that was the reason why the idea of such a nonreciprocal, virtual antenna vector (at first announced in [2]) was never used before.

An idea of the suboptimum receiver is based on application of three receiving four-vectors, mutually perpendicular, and perpendicular to the Stokes four-vector of clutter. Then, after multiplication of the received four-vector of 'signal plus clutter' by the three receiving four-vectors, the largest product can be selected as the received nondisturbed signal. The three receiving four-vectors can be obtained easily by such three rotations of the coordinate system of the four-dimensional real space that the first coordinate axis coincides with the clutter four-vector. Thereupon, the three remaining coordinate axes determine the requested receiving four-vectors.

The four-vector of the undisturbed signal will not necessarily be pointing along one of these receiving four-vectors. In the worst case, it can be equally distant from all their directions. Then, the loss caused by using the suboptimum receiver will count about -2.5 dB. However, construction of an optimum non-coherent receiver also appears to be possible. The receiving four-vector can be chosen as parallel one to that component of the wanted signal which is perpendicular to the clutter.

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Analysis Methods of Experimental Mueller Matrices

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Mueller matrices generally describe the action of optical systems on electromagnetic waves. These matrices contain all system's polarization and energy information for a given configuration. Mathematically, these matrices act as a linear operator on Stokes vectors defining the incoming wave this yielding a mathematical formalism known as "Stokes-Mueller formalism" to treat polarization in a coherent manner. The main interest of such approach is due to addition theorem of Stokes vectors and to optical equivalence principle allowing decomposing a general matrix as the incoherent sum of matrices representing "simpler" process.

This paper deals primarily with the analysis methods of system's measured Mueller matrices. Problems of physical realisability are also considered.

After introducing the state of the art and the most recent literature results we propose a new decomposition of experimental matrices giving access to the main interaction process wherever it exists and to isotropic and anisotropic depolarizing properties of the target. The matrix is written as the sum of two independent Muller matrices and this is quite general since it allows decomposing any real matrix having sixteen degrees of freedom. This decomposition provides a geometrical interpretation of the action of the system and a simple representation of it can be illustrated on the Poincare sphere.

Finally, a general analysis algorithm is proposed to treat experimental data and illustration with real measurements is made thanks to a new experimental setup for polarized bi-directional scattering studies in the infrared wavelengths domain.

Signal Received by a Bistatic Radar from a Moving Target : Applied to a Canonical Target

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The improvements in the furtivity techniques considerably reduce the detection performances of most radars working at the present time. The desire to always know more and more information about the characteristics of the detected target has led to the development of a new generation of radars. These radars, called vectorial bistatic radars, allow us to determine the polarimetric characteristics of the target, and also to fight against furtivity. When the target is moving in a complex propagation environment, it is possible to improve its discrimination power using its polarimetric characteristics. A polarimetric study of the signal received from the target also allows us to identify the target. This paper deals with the remote detection field or the radio link field. This study concerns the modelization of the signal received by a vectorial bistatic radar from a moving target.

The Doppler effect caused by the moving target generates some distortions on the signal during its propagation between the transmitting antenna and the receiving antenna. Therefore, the frequency of the received signal from a moving target is shifted from the transmitted frequency by the Doppler frequency which is a function of the projection of the velocity of the target in the direction of the transmitter and in the direction of the receiver.

First, we present the waveform of the transmitted signal. In order to improve the performance of the range ambiguity and the velocity ambiguity of the radar, the transmitted signal is chosen as a compressed pulse. The pulse compression is realized using a rectangular pulse with a linear frequency modulation.

In order to study the influence of geometrical and physical characteristics of the target on the polarization of the received signal, the transmitted signal is considered as a vectorial signal transmitted with a particular polarization. The transmitted signal thus is considered as an electric field.

The field scattered in the direction of the receiving antenna and the field incident on the target are linked by the scattering matrix [S] which is a 2x2 matrix. This matrix defines the polarimetric behavior of the target. The coefficients of this matrix depend on the frequency of the incident wave, the physical and the geometrical characteristics of the target, and the geometry of the radio link.

We present in this paper the signal received by a vectorial bistatic radar from a target. We present the general case where the transmitter, the target, and the receiver are moving with constant velocity. The simulations are realized in accordance with the canonical targets.

Session J02
Tuesday, July 14, AM 08:40-11:20
Room 450
Microwave Scattering From Rough Surfaces

Organiser : P. Pampaloni
Chairs : P. Pampaloni, S. Paloscia

Synergic Use of Altimeter and Scatterometer Data for non Fully Developed Sea-State Parameters Retrieval

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A two-scale model based on a boundary perturbation approach is used to compute backscattering coefficients from the ocean surface. The waves system is considered in non-fully developed state. The gravity range parameters are the peak wavenumber and the significant slope. The capillary range is derived from very recent wavenumber spectrum measurements in tanks and ocean. It is entirely determined by the wind friction velocity over the surface. The angular function is a simple Fourier series extended to the second harmonic. This first harmonic is taken as zero, and the second one is related to the ratio of slope variances in upwind and crosswind directions.

Numerical calculations of radar backscattering coefficients are performed for wide ranges of wind speeds and for values of the significant slope usually observed in ocean conditions. Two frequencies (C and Ku bands) and several incidence angles are considered. The model is shown to be consistent with TOPEX C and Ku Bands altimeters measurements, and ERS-1 and SASS C and Ku Bands scatterometer empirical models as well.

Based on this model, a synergic inversion algorithm allowing any combination of microwave instruments (radiometers and radars) has been developed. Radar scatterometer (ERS1-2) and altimeter (TOPEX, ERS1-2) are then inverted with this procedure to retrieve the wind vector and the significant slope parameter. The inversion is constrained on the value of the significant wave height retrieved from the altimeter response. Therefore, the inversion procedure yields the wind vector, the height variance and the peak wavenumber. The results are next validated using collocated ECMWF wind fields and discussed. Limitations of the inversion algorithm are pointed out and improvements are proposed in term of instruments precision or channels combination.

A Monte Carlo Code for Backscattering from a Ground in the Presence of Scatterers Modelling Vegetation Elements

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The scheme of a Monte Carlo code originally developed at Florence University, Department of Physics, for calculating lidar returns from clouds and fogs, has been the basis for a new version aiming at modelling the scattering of a ground covered with vegetation.

The essential part of the code is the determination of trajectories. They are initially straight lines representing a discretization of a microwave radar beam. Inside the sounded medium the trajectories are bent at scattering points determined by the code according to probability laws depending on an extinction coefficient profile with height (from ground). The medium is modelled as a continuum one, whose properties (extinction coefficient, albedo , scattering matrices) depend on the number density and sizes of simple shape scatterers : cylinders, ellipsoids and spheres representing vegetation elements. The probability of scattering by each type of scatterer depends on the partial relative extinction coefficients of them.

The ground is modelled as a planar rough surface. Trajectories incident on it are partially reflected and transmitted. Direction of reflection is determined according to the intensity scattering pattern depending on incidence direction and ground roughness properties.

At each bending point a weight is applied, equal to the local albedo, to the energy of a trajectory (initially considered unitary) and energies of trajectories ending on a receiver area in the far field are simply added. Incoherent scattering is taken into account. Polarization change of a trajectory is followed by using Stokes vectors and scattering matrices.

As for spheres Mie formalism is used to calculate the scattering properties. Scattering by finite cylinders is calculated according to approximation procedures (surface and volume currents equal to those for an infinite cylinder).

The limits of the incoherent adding of scattered radiation will be checked by considering some simple situations.

Characterisation of the Soil Roughness and Microwave Backscattering Based on Fractal Brownian Description

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Electromagnetic scattering models for the analysis of microwave remote sensing data require adequate descriptors of the geometrical properties of soil surface. The rms height and correlation length have been extensively used for the classical electromagnetic models. These parameters seem insufficient to provide a correct physical understanding of soil backscattering. To get a finer soil representation, the proposed approach uses three dimensional images of the soil surface obtained from stereovision photographs. The numerical surface reconstruction is computed over a 1m by 1m section of natural surface with a sampling step of 1mm. This three dimensional soil topography has been validated by a comparison with a laser-profiler. Different types of agricultural surfaces are considered : smooth, sowed, cloddy and ploughed soils from experiments done on the INRA-Grignon sites (France).

Our approach is based on the description of soil at two scales; first, the large scale defined by the rms height and correlation length and second the small scale which correspond to the local structure of soil described by the fractal brownian model developed by Mandelbrot.

For the local structure, the brownian model defines a parameters: the fractal dimension. The calculation of this parameter over the 3-D images for different data base soils demonstrates their fractal local structure. The same computation for different profiles in every image (1000 lines and 1000 columns) shows two results; first, the good stability of this parameter and second its capability to discriminate the different practices of soil tillage.

Experimental correlation functions are found to be generally intermediate to the exponential and gaussian forms. On the other hand, backscattering is very sensitive to the form of this function with a large scatter in radar level. It is important to determine the right shape of this function. From the brownian fractal model formulations, we propose a formulation of an analytic fractal correlation function depending on fractal dimension. The same fractal approach is used for deriving pertinent correlation length. For different tested profiles (lines and columns from the 3-D images), the experimental correlation functions show a very good agreement with the derived fractal function. Comparisons of these new descriptors are done with the classical ones(rms height, correlation length) and show good agreement with a reduced variability of the former. In fact, this fractal method is few sensible to local fluctuations in profiles.

The method of moment is used to evaluate the scattered field in co polarisation from generated soil profiles in the case of perfect conductor. The profiles generation is based on the random midpoint displacement method for the description of the local structure combined with the large scale description defined by the rms height and correlation length. To check the validity of these backscattering simulations, numerical results are compared with analytic solutions of IEM (Fung et al, 1992). A good agreement is obtained for profiles within IEM validity domain.

Validation of a Fractal Brownian Modelisation of Bare Soil and its Backscattering Behaviour Using SIR-C and ERASME 1994 Data Over Orgeval

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The SIR-C/XSAR experiment of April 1994 over the Orgeval pilote Watershed(France) gives the opportunity to access to SAR images over an entire region (4x4km2). During the shuttle radar mission, the Orgeval site remained in high conditions of soil moisture. The remaining factor of variability over bare soils was roughness. The watershed cover in April consisted of a majority of bare soil with a variety of soil practices (sowed and ploughed fields). To complement the shuttle radar data provided (44 to 57°) by comparable data, the CETP helicopter borne scatterometer ERASME was deployed. It operated in C band from 25 to 50°. For ground truth, ten fields representative of the crop practices were intensively characterised. Soil moisture and density measurements and height profiles by pin-profilers were done. A SPOT image was used to assess the fields boundaries.

The rms height and correlation length extensively used for the description of roughness seem insufficient to estimate backscattering from bare soil. Therefore, we propose the validation of a new approach based in the description of soil in two scales. The small scale within few centimeters is characterised by the fractal dimension which corresponds to the variability of local structure. The large scale is determined by the rms height and a pertinent evaluation of the correlation length founded in the brownian fractional model.. It is applied to the ten fields of the site. For different soils, we identify the fractal local structure. The fractal dimensions were found to range between 1.2 to 1.65. In the majority of cases, the more the rms height is important, the more this fractal dimension is small. The parameter, calculated for 10 profiles within a same field shows a good stability.

Experimental correlation functions are found to be intermediate to the exponential and gaussian forms. The choice between an exponential fit and a gaussian one is insufficient because backscattering is sensitive to the shape of the correlation function. Then, it is important to get the closest shape to the experimental one. Fractal brownian model, used for this description provides an analytical correlation function. For the different profiles, the experimental correlation functions show an excellent agreement with the brownian one. This result validates the dependence of the correlation function form on fractal dimension and then on the local structure of soil.

The method of moment in dielectric conditions is used to evaluate the scattered field in copolarisation for different fields. Introducing large and small scales, we generate numerical 2-D soil profiles based on brownian structure. Numerical backscattering simulations for different fields were compared with SIR-C and ERASME radar measurements. They show a good agreement for different roughnesses. Interesting conclusions are drawn especially for smooth soils (slaked and precipitation) and rough ones.

Evaluation of Sensitivities of Soil Moisture and Surface Roughness Parameters on SAR Measurements

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Estimates of soil moisture are of great importance in numerous environmental studies, including hydrology, meteorology, and agriculture. This study shows our continue efforts on developing and testing the algorithm for retrieval soil moisture and roughness parameters using L-band polarimetric SAR data.

Several algorithms for soil moisture and surface roughness estimation from L-band co-polarized SAR image data have been developed. The tested results from SIR-C and AIRSAR data indicated a fairly good agreement with the field measurements. The common idea from these algorithm is to separate the expression of the backscattering coefficient into two parts - a roughness function which only depends the surface roughness parameters and a dielectric function (or polarization magnitude) which only depends on the surface dielectric properties.

In this study, the sensitivity analyses were carried out by the data from the ground scatterometer measurements and the data generated by the Monte Carlo simulations. The results from the sensitivity analyses indicate that the sensitivity of backscattering coefficients to soil moisture and surface roughness parameters varies at different frequencies and polarizations.

Depending on the normalized roughness parameters: ks and kl, both dielectric and roughness functions can have a significant different expression. Based on the results from sensitivity analyses, we modified our algorithm and performed on the experiment data that were conducted in June, 1992 at the Little Washita watershed near Chicksa, Oklahoma with the NASA/JPL airborne imaging radar polarimeter.

We will show (1) the evaluation of sensitivities of SAR measurements on soil moisture and surface roughness parameters. It aims on improving and developing the algorithm for soil moisture and surface roughness estimation from real SAR measurements, (2) a modified soil moisture retrieval algorithm for a random rough surface, and (3) test using L-band AIRSAR.

Microwave Backscattering from Bare Rough Soils : a Comparison of Experimental Data and Surface Scattering Models

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The operational capability of remote sensing for monitoring soil parameters by radar is not yet fully explored and extensive research is being carried out to assess the achievable reliability and accuracy of measurements. The study of scattering from rough surfaces by means of electromagnetic models can contribute to better understand the interaction between the electromagnetic fields and natural surfaces, and to develop inversion algorithms for the retrieval of soil parameters.

In this paper the effects of surface roughness on microwave backscattering of natural soils have been analysed using SAR data collected by different SAR systems (ERS-1, JERS-1, AIRSAR and SIR-C/X-SAR) in a frequency range between 1.2 GHz and 9.3 GHz and at different incidence angles between 20° and 50°. The surface parameters have been characterized in terms of standard deviations of surface heights (HStD) and correlation length (L). In the observed surfaces, the HStD ranged from 0.8 to 3.5 cm and only data with almost constant value of soil moisture (close to 20%) have been used for this study. It has been found that, in the range of observed roughness, the highest correlation to surface HStD was found at L-band q > - 35E. The model taken into considerations in this study are based on the well known approximations: Small Perturbation (SP), Physical Optics, (PO), Geometrical Optics (GO), and Integral Equation (IEM).

A major problem in modelling scattering from rough surfaces is that real surfaces may not well represent the approximations introduced by the models since, in general, the autocorrelation functions of natural surfaces are complex and do not have an analytical form. To simplify the problem of validating the analytical models, experiments on artificial surfaces realized with the same surface and dielectric characteristics used in the electromagnetic models, have been carried out at the European Microwave Signature Laboratory (EMSL) (JRC-Ispra (I)), where polarimetric scattering measurements were carried out in the anechoic chamber over a frequency range between 2 and 18 GHz at various incidence and scattering angles between 10 and 50 degrees. Three different experimental models, composed by an artificial dielectric with stable permittivity, similar to the one of soil, and azimuthal isotropic surfaces have been tested. The combination of the surface parameters with the frequency range of the sensors allowed one to cover a large part of validity range of electromagnetic models. The comparison between the measurements and the model calculations has confirmed that the IEM has a wider range of applicability with respect to other classical approximations. The simulated backscattering coefficient is in agreement with the measured one within the limits of experimental errors except for frequencies higher than 10 GHz when the incidence angle is higher than 30 degrees. In the latter case, as the frequency increases, the measured backscattering tends to a constant value, whereas model prediction indicates a decrease.

Characterization of Areas Contributing to Runoff with SAR Images in FLOODGEN Project

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FLOODGEN is a European project supported by CEO* programme. Its aim is to encourage the use of remote sensing data in management against excessive runoff. In this project, a specific study was carried out to assess the potential of using ERS-2 and RADARSAT images in runoff modelling. The main objective was to identify a parameter that characterises the surface condition - i.e. soil roughness - a factor that influences both runoff and radar backscattering.

The test sites are located in Europe and in Canada. They are dominated by loamy soil and agricultural plots. Simultaneously, ERS-2 and RADARSAT data have been acquired and ground field observations have been realised. Soil moisture and vegetation cover were evaluated and different roughness parameters were measured :

-quantitative roughness parameters corresponding to hydrological models

-statistical roughness parameters (standard deviation of height and correlation length) corresponding to backscattering phenomena

First of all, the different roughness parameters, necessary for runoff modelling or for backscattering modelling, were compared. Results allow to assess what kind of hydrological description could be approached through radar images.

Secondly, the best configurations of RADARSAT mode, adapted for extracting agricultural roughness parameters, were evaluated using ground parameters and theoretical models.

Finally, backscattering coefficients for each plots have been extracted from images and compared with ground parameters to identify the real potential of the satellite images.

* CEO : Center of Earth Observation, european initiative DGXII

Key Words : Remote sensing; SAR images; RADAR; backscattering modelling; roughness.

Session K02
Tuesday, July 14, AM 08:40-11:40
Room J
Oblique Incidence Ionospheric Sounding : Theory and Observations

Organiser : L. R. Cander

Chairs : L. R. Cander, M. F. Levy

Ionospheric Propagation Modelling with the Parabolic Wave Equation

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The parabolic wave equation (PWE) is a paraxial approximation of the wave equation which can be used to represent the field propagating forward in a non-homogeneous medium. The solution can be marched forward in the Earth-ionosphere waveguide, given the refractive index structure and appropriate boundary conditions on the Earth surface. One of the advantages of this full wave method is that it calculates field strength directly at all points of the computational grid. Caustics do not cause any particular problem, and results are easily obtained near the skip distance. Another strong point is that surface and sky wave effects are treated simultaneously. Antenna patterns are taken into account when defining the initial field. The main drawback is that the quantity computed is the total field, and that it cannot be easily decomposed into a sum of partial fields due to different rays arriving at the same point, as would automatically happen in a ray-tracing model.

Here we present a 2-dimensional version of the method, neglecting transverse variations of the refractive index. There is no difficulty modelling horizontal gradients along the path: the PWE algorithm reads in vertical electron density profiles along the path, simply given as numerical tables. The refractive index is complex, so that we can deal with collisions and model a lossy ionosphere. The O and X modes are computed separately and can be added if necessary to obtain the total field strength. Extension to 3-dimensional calculations through azimuthal coupling is possible, but more time consuming.

On the Methods for the Description of HF Propagation in the Real Ionosphere

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A great variety of spatial and time parameters are pertinent to the real ionosphere, characterizing the spatial and temporal behaviour of the ionosphere. As the time scale of the ionospheric nonstationarity are rather large compared with the time relaxation of the ionospheric plasma and the periods of oscilations of the HF fields, the most problems of HF ionospheric propagation may be considered in the quasistationary approximation. Even in the scope of this approximation one faces the complicated problems of wave propagation in manyscale inhomogeneous media, which do not provide the separation of variables in the appropriate equations. Generally the greatest scale characterizes the undisturbed background ionosphere and the rest smaller scales pertain to the local inhomogeneities of the ionosphere (ionospheric disturbances).

As is seeing at present the theory of HF propagation in 3D smoothly inhomogeneous background ionosphere is fully completed. It is based on the geometrical optics approximation or its generalizations in the form of the integral representations in terms of the geometrical optics type component waves while treating the fields in the singular areas of the field of rays of the problem under consideration (caustics etc.).

The modern theory of HF propagation in the ionosphere has to provide the description of the fine effects of propagation, caused by local inhomogeneities of the ionosphere. These are the ionospheric turbulence, TIDs, manmade local inhomogeneities and so on. As one understands some of the effects of propagation due to local inhomogeneities need the stochastic treatment (effects due to the ionospheric turbulence), others may be considered in the deterministic statement.

This way, the state-of-the-art theory of HF propagation must take into account regular refraction due to the inhomogeneous background ionosphere together with the scattering effects by local inhomogeneities, including the diffraction on local inhomogeneities of nonzero values of the diffraction parameter. To describe all the effects mentioned together we develop the method of the complex phase for the fields in smoothly inhomogeneous media with local inhomogeneities embedded. The method generalizes classical Rytov's approximation to the case of inhomogeneous background media. First generalization has been performed in [1], where the main term of the ray expansion of a point source field in smoothly inhomogeneous medium has been used as the incident field. As the further generalization the integral representation of the field by diffracting component waves has been developed ion [2-4], where each diffracting component wave is constructed by making use of the complex phase.

In the scope of the approach proposed a lot of problems of HF propagation in the disturbed ionosphere have been considered. Among them the diffraction of the HF field on a modified area of the ionosphere and on TIDs [4], treated in the deterministic statement, as well as a series of problems of propagation in the fluctuating ionosphere, considered as the stochastic problems. These are HF field phase and amplitude fluctuations characterization [5], pulse propagation through the fluctuating ionosphere [6-8], the ionospheric scattering function in the HF band [9].

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Statistical Characterization of Time Variability in Midlatitude Single Tone HF Channel Response

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Design and development of efficient and reliable communication systems in HF band require statistically reliable characterization of the ionospheric channel at various time scales. Recent developments in system identification and adaptive filter theories enable efficient and reliable modems to be built for the complicated HF channel structure with increased bit rates and reduced bit error probabilities. Most of these modern signal processing algorithms used in smart modems estimate the variability of the channel through the first and second order moments of the received signal.

In this paper, a statistical analysis approach is proposed to characterize the variability of the HF channel response to single tone signals by using only the amplitude information of the received signal. By the proposed methodology, robust estimates to the time varying mean and variance of the channel response can be obtained. For this purpose, we use sliding window statistics of the available data. The window size is chosen as long as possible to provide better estimates and still short enough to capture the underlying time variation of the channel response. Based on estimated variance of the obtained results, detailed justification on the proper window size is given. In order to obtain more reliable estimates, the data is median filtered prior to its statistical analysis. A robust way of choosing the length of the median filter is presented. We applied the statistical analysis approach to a set of available data obtained from a measurement campaign between the United Kingdom and Turkey conducted from April, 1992 to February, 1993. The results of the statistical analysis confirmed the expectations on the physical behavior of the ionospheric channel. It is found that the midlatitude single frequency channel is slowly time varying and locally stationary in a sliding window of 22 seconds. Also, it is observed that the amplitude of the received signal exhibits a significant diurnal variation. In addition, during early morning hours and night hours, the channel is considerably more stable for communication purposes compared to day and early evening hours.

Short-term ionospheric forecasting over Europe

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Short-term ionospheric forecasting tools have become an essential requirement for radio communications in the HF band, and also for global positioning applications. We describe an operational tool for the European region based on continuous monitoring of the ionosphere. This is intended to be available on the World Wide Web for interactive use.

A network of ground-based vertical incidence ionosondes provides the basic inputs for the region of interest (10^0 W - 90^0 E, 30^0 - 70^0 N). Data are currently updated every 24 hours. Short-term forecasts of the critical frequency foF2 of the F_2 layer and of the propagation factor M(3000)F2 are then produced using both neural network and auto-regressive algorithms. Contour maps of foF2 and M(3000)F2 are drawn using Kriging interpolation techniques.

A ray-tracing tool is included for HF communications planning. For real-time applications speed is the first priority, and we use a simple analytical ray-trace. The input for this is a mid-path electron density profile based on the IRI model, which has the advantage of only requiring foF2 as input.

This work would not be possible without international collaboration to provide the necessary ionospheric data on a daily basis. This has been greatly facilitated by the framework of European project COST 251, and we wish to acknowledge here the contribution of our COST 251 colleagues.

Ionospheric Variability Seen by Oblique Sounding Data

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The various forms of temporal ionospheric variability consist of both systematic diurnal, seasonal and solar-cycle variations and large irregular day-to-day electron-density fluctuations. The characteristic features of variations which correspond to the ionospheric climatology are basically well understood and can be successfully predict. However, fluctuations associated with the irregular ionospheric structures of different scales which correspond to the ionospheric weather are still important scientific issue relevant also to the HF electromagnetic waves propagation. This requires a systematic study of all available ionospheric measured data during different local times, seasons and levels of solar activity.

A large quantity of oblique incidence ionospheric data obtained in the European area have been collected and studied with the aim of constructing the statistical patterns of ionospheric variability. Here data obtained from the network of oblique soundings in Sweden are analysed to reveal the off-median features of the high frequency parameters such as the maximum observed frequency (MOF), the maximum usable frequency (MUF) and the lowest observed frequency (LOF). The results support the view that day-to-day F region ionospheric variability is essentially altered during large solar-terrestrial events.

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Results from the 1997-98 UK Oblique Sounding Campaigns

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Results and analysis are presented here from a series of observational campaigns conducted in the UK during the period of summer 1997- spring 1998. A wide variety of oblique paths (1300km, 550, 400, 370, 120, 50 km) spanning the UK were covered in conjunction with vertical sounders. The oblique sounders used were the IRIS (Improved Radio Ionospheric Sounder) chirp receiver developed by DERA Malvern and IRIS compatible chirp transmitters. The broadcast signal is a 10W phase continuous 100kHz/s chirp extending from 2 to 30MHz. GPS synchronization between transmitter & receiver provides a measurement of absolute group delay to an accuracy of less than 10μs. The measurement campaigns included a north-south chain of comprising of two transmitters and three receivers with a pseudo-vertical short-hop measurement at the mid-point and the Chilton and Lerwick vertical Digisondes (DPS Digital Portable Sounder) approximately at either end of the longest path. A separate east-west campaign centered on the Chilton Digisonde and a very short-hop (50km) pseudo-vertical co-located with the Chilton Digisonde were also conducted. The analysis presented includes an examination of the validity of mappings between vertical and oblique ionograms using real data over a selection of ground ranges and instrumental comparisons between chirp and digital soundings methods at vertical incidence. An investigation is also presented of vertical and oblique ionogram to electron density profile inversion techniques (POLAN and after Reilly 1989) and a comparison of the results of both numerical and analytical ray-tracing on the N(h) profiles with the experimental observations.

Theory of Ionospheric Propagation : Distance between Theory, Experience and Model

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The electromagnetic wave propagation in the ionosphere is probably one the most complex. The medium is dispersive, inhomogeneous and anisotrope. The theory of the propagation in a such medium has been largely developed for a long time, but methods of Maxwell equation resolution are always in evolution taking into account the more and more accurate modelisations which are necessary for sciences developments in this area. The non stationarity of the ionosphere introduces new dimensions for physical modelisations as well for electromagnetic wave propagations (OEM) and developed models are enough numerous.

The physics of the ionosphere is classed in the continuous medium area for which the higher complexity of studies is well known. It notably spreads out natural chaotic or induced by artificial modifications phenomena. Their representation and the propagation of OEM, in these particular conditions, have been particularly studied last decades for multiple reasons. Theories, measures and models have been undertaken for the fundamental research but also for systems - such the GPS –which needs more and more accurate models. The computer tool has become the preferential partner of the theorist that allows to extend their calculations.

The theories of the propagation have developed notably in function of objectives. An analysis and a classification is made and areas of validity are examined. Results obtained with these different theories are examined by comparing them to experimental results obtained in electromagnetic soundings of the ionosphere and in indirect or direct measurement of transmission sub- ionospheric or trans-ionospheric channels. A discussion on limit of current methods and the utility to develop new methods is made by taking into account available means to measure parameters of the medium, to anticipate some evolution and the necessity to decrease thresholds of discernability as well for the physics of the medium as for the characterization of transmission channels.

Extremely Low Power Vertical and Oblique Ionospheric Sounding

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Extremely low power for vertical and oblique ionospheric sounding remains nowadays the main technique of exploration of the ionosphere. Used in a first time in bistatic oblique and zenithal sounding methods for the study of the physics of the medium, these techniques have been extended with the method of backscattering retrodiffusion at the end of 50's. Currently, these methods of soundings are used in order to evaluate transmission channels and their implementation in systems is foreseen with short-dated operational projections. These methods of sounding allow the access to main parameters of the medium, such as critical frequencies, maximum ionization height, ionization profiles. But since years 70's, the use of the scattering function has been made, first to characterize the medium, then now to characterize propagation channels. Their utility is therefore double and concerns as well physicists as telecommunications engineers.

The main disadvantages of ionospheric sounding by classic methods comes on the one hand from the spectral congestion of the decametric range that disturbs considerably measurement, but also from used powers in sounders, adding so an intolerable disturbation since it is made on all the range of frequencies with non negligible powers. If sounders emissions are sometimes tolerated, they are always illegal and lead more and more frequently to financial penalizations for users of sounders that emit in reserved bands. To respect the legislation, soundings would have to be made on a reduced number of frequencies that, most of the time, forbid a sufficiently correct extraction of researched parameters.

A henceforth accessible solution consists in reducing significantly emitted powers. It can, indeed, be noticed that if emitters powers remains in the order of magnitude of the Watt or lower, signals after a reflection on the ionosphere can only be picked up to the ground with levels inferior to the ambient noise. From then on, one can no longer reproach to these emission to be seen as a disturbation. To realize such soundings two constraints have to be respected :

- The sounding duration does not have to exceed those habitually accepted. It can be estimate that a duration of about 1 minute is needeed, and that it does not have to exceed 10 minutes.
- The low power has to maintain sounding qualities at the same level than those obtained with classical power, in order that estimation errors on extracted parameters should not be superior than in classical soundings.

The respect of these two constraints, to which it is necessary to add the natural constraint to made measurement during the channel coherence time, puts the problem under new forms that can henceforth be resolved with the development of signal processors and the implementation of new coding and processing signal techniques.

Presented methods allow to carry out sounding in respecting these constraints and in ensuring a very good results quality. Used methods are rapidly described and illustrated by examples putting in obviousness the good obtained result quality and, notably, their resistance to interferences so numerous in the decametric band. Results are compared with those obtained with classical known methods of coding and signal processing.

It is shown that, in operationnal conditions, used powers can be reduced to values of about 1 Watt for zenithal and oblique bistatic sounding in respecting times constraints imposed on these sounding. In the case of backscattering soundings, it is shown that it is possible to use light stations, for example equiped with an log-periodic antenna adjustable in azimuth and using powers inferior to 100W.

With such low powers, it is nevertheless possible to made excellent quality measurement with extreme resolutions of about 5 kilometers for backscattering sounding as for oblique bistatic and zenithal sounding. Measures of scattering functions can be also made and rapid measure methods allow to acquire them in real time with very short times of analysis. The obtained result quality allows to implement new analysis methods such as the fractal measurement of scattering functions. These new measures obtained thanks to high resolutions allowed by these methods open a usefull exploitation field as well physicists as for telecommunications technicians. Indeed, it is shown that these measures are correlated with geophysical parameters and that telecommunications system performances depends on them.
A series of examples illustrating advantages that offer such methods is presented in conclusion of this communication.

Session L02
Tuesday, July 14, AM 08:40-11:40
Room R01
Biological Effects

Organisers : J. Wiart, B. Veyret
Chairs : J. Wiart, B. Veyret

Key Issues for the Evaluation of Interactions between a Hand-Held Radiotelephone and the User

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The analysis of interactions between hand-held radiotelephones and the user not only refers to the electromagnetic power absorbed by the human body but also to the radiated power transmitted towards base stations. Absorbed as well as radiated power depend on a great amount of parameters, such as electromagnetic properties of the head, position of the handset near the head, position of the hand on the terminal, design of the antenna and its integration on handset, operating frequency... The relevance of each of these parameters remains a great challenge for research in electromagnetics.

Near field measurement techniques have been developed for the evaluation of local Specific Absorption Rate (SAR) that represents the power absorbed per mass unit of tissues. They are based on robot controlled E-field measurements within a model of the human body (phantom) filled with tissue equivalent liquid [1]. Exhaustive research is still needed in order to ensure that dosimetric assessments are related to the real use of handsets and that measurement protocols are reproducible and accurate. Guidelines for the standardization of SAR mesurements will be proposed.

Far field measurement techniques have been developed in order to derive 3D radiation patterns and the total power radiated by the handset [2]. The ratio of total power radiated by the handset alone and near the phantom is of great interest for the understanding of interactions with the user. A great effort is also needed in order to standardize such protocols and improve post-processing of 3D radiation patterns.

Simulation tools provide very good support to measurement techniques. Most of the current studies are based the Finite Difference Time Domain (FDTD) method because it allows complex modeling of the human body [3]. But finite element or boundary element methods are convenient for modelling different positions of the handset near the phantom. In both cases, validation of the numerical model of handsets must be made by comparison with far field and near field measurements. Then, simulation can be used to investigate the interaction with different types of phantoms. They are also very helpfull for the validation of measurement protocols. Typical examples will be analysed at the conference.

Mobile/user interactions still challenge research in electromagnetics. This complex problem must be addressed by specific near and far field measurement techniques as well as powerful simulation tools. The evaluation of power absorbed by the user and local SAR must always be confronted to the analysis of the efficiency of the handset near the user.

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Exposure Device for Applying RF/Microwave Fields to Biological Preparations

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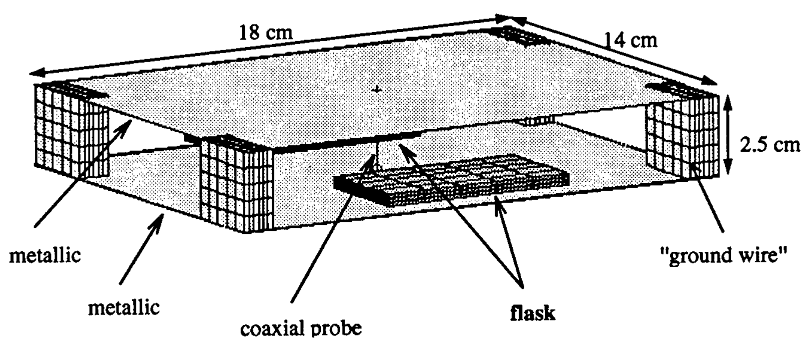
The aim of studies of the effects of microwaves at 900 MHz on biological materials is to isolate a tissue to analyze the changes in the properties of individual cells, related directly to dosimetry. In this context, we designed a new exposure device.

Often, in bioelectromagnetics, *in vitro* biological experiments on cell cultures are performed in Crawford transverse electromagnetic (TEM) cells. The advantages are their relative affordability and their ease of use. Nevertheless, TEM cells should be used only with caution for *in vitro* studies : well matched, area of the homogeneous field distribution and the induced specific absorption rate (SAR) are around 10-50 mW/kg for one watt incident power, at 900 MHz.

A new system was studied, designed and constructed, to isolate cultures of biological cells. This structure is easy to construct and presents the following advantages :

- Good homogeneities of the SAR distribution. To improve homogeneities, we used two different Petri dish, one inside the other.
- The SAR values obtained with this system are around 250-500 mW/kg for one watt incident power at 900 MHz.

Different kinds of biological support can be used, 24-well plate, 33-mm Petri dish or flask. This system is based on the Wire Patch antenna, which presents the advantages of working at 900 MHz with a homogeneous field between the metallic patch (see figure). Of course, it is a radiating structure, with the same radiating pattern of dipole, and we need some absorbing materials around the system. The bandwidth of this device is less than 5%, but it is possible to place up to 8 Petri dishes into one structure.



Now, we will used this device with different biophysics or biology laboratories (B. Veyret-Bordeaux, L. Mir - Villejuif, J. Teissie-Toulouse). We shall also design a system such that it will allow confocal microscope imaging of cell sample.

Numerical and experimental evaluation of E-field and absorbed power in the pelvic region using a bone-equivalent phantom

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Electromagnetic dosimetry is of basic importance for the investigation of the biological effects of electromagnetic (EM) fields. In this widespread area the dosimetry is necessary e.g. for applicator quality assurance and verification of treatment planning in hyperthermia (HT) or for evaluation of the exposure of human tissues to the field emitted by antenna systems used in mobile communication (MC). Even if the deposition of the EM energy into human tissues has an opposite function for both application fields (necessary for HT/ disturbing for MC) the used technical and numerical framework is related or identical. Thus, results and observations gained in one application field can be applied in the other. The purpose of this paper is to evaluate the behavior of EM fields numerically and experimentally for a geometry related as close as possible to human one (here pelvic region). Especially, we are interested in the investigation of locations of so called "hot spots", i.e. regions of high field and/or specific absorption rate (SAR) values in healthy tissue, thus in general case being a disturbing factor for both, HT and MC applications.

In order to measure the EM fields in an anatomically realistic situation, a combined bone/fat/muscle - equivalent phantom has been developed. The heart of this phantom is a cast of a human skeleton made of a bone-equivalent mixture of polyester resin and graphite [1]. This bone-equivalent structure is situated inside of an elliptic phantom filled with a saline solution for simulating the so called "2/3-muscle" tissue (average of muscle/intestine/inner fat). The walls of the elliptic phantom are fat-equivalent, thus simulating subcutaneous fat tissue. Inside the phantom catheters are positioned for measuring of E-field and SAR-values with E-field probes or temperature probes at certain well defined locations. CT-scans of this phantom are then used as input for segmentation/field calculation, which are supported by our visualization platform "HyperPlan"[2], based on open-inventor concepts. Using "HyperPlan" we can quite exactly simulate the position of the catheters and measuring points. As excitation sources we use dipole antennas. For calculation of E-field we are applying different methods based on voxel and tetrahedral grids (finite difference time domain (FDTD), volume surface integral equation (VSIE) [3]).

The obtained numerical results are in fairly good or good agreement with the measurements. The numerically predicted locations of "hot spots" are in a good correlation with measurements.The greatest differences between measurements and simulations are occurring near tissue interfaces or interface combinations, where also the numerical results differ depending on used segmentation kind and E-field calculation method. For further comparison finer resolution of numerical models/methods and smaller size of E-field probes are necessary.

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Effects of GSM Microwaves on Lipoperoxidation and DNA Fragmentation in the Brain of Rats

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In view of the huge development of mobile communications, concerns about the health aspects of radiotelephone use have been expressed. Research is being performed worldwide to investigate biological effects and health consequences. Recent results by Lai and Singh (1995) showed that exposure of rats to 2.45-GHz pulsed microwaves led to single- and double-strand breaks of DNA. These data were not confirmed by the Roti Roti group in St Louis using different exposure and analysis protocols. In order to clarify the issue, we are currently doing an experiment in which groups of 18 rats are exposed to 900-MHz GSM microwaves (head-only, SAR of 2 and 4 W/kg, 1-hour exposure). Animals are sacrificed immediately after exposure and brain cells are set in agarose, lysed and electrophoresis is performed showing « comets ». We are also looking at the lipoperoxidation of brain cells since brain tissue are susceptible to the action of free radicals because of the large amount of fatty acids in the membranes of cells and the limited presence of antioxidant species. This study is done on groups of 16 rats exposed for 1 hour/day during 5 days (GSM 900 MHz, 2 and 4 W/kg, 8 rats exposed and 8 rats sham-exposed). Lipoperoxidation is assayed by measuring the amount of malondialdehyde formed. These two approaches should help us understand better the role of free radicals in the potential biological effects of radiotelephones.

Lai H. and Singh N. (1995): Acute low intensity microwave exposure increases DNA single starnd breaks in rat brain cells. Bioelectromagnetics, 16: 207-210.

This work is supported in part by the research center of France Telecom (CNET).

Health effects of mobile phones : human studies

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Mobile phones expansion has raised concerns about the eventual health risks from microwaves exposure. The main worry about cancer has been widely addressed, mostly with negative answers, but some other claims such as headache, neurological diseases, or hypersensitivity still remain.

Laboratory in vitro and in vivo experiments can be helpful in orienting the answers, but they are not always easily extrapolated to humans. Moreover, if long term effects are to be suspected, results of epidemiological studies will be known only after some years. Furthermore, there must be an initial detectable biological effect before any actual pathology is considered. Therefore, studies were performed in our laboratory on the effects of mobile phones on human physiology. From the litterature, research was oriented towards the endocrine system and the nervous system.

Research on the endocrine system :

In our laboratory, we studied the effect of mid-term exposure (2 hrs/day, 5 days/week for 4 weeks) on the secretion of hypophyseal hormones and melatonin. In a first set of experiments, we looked at the basal level, once a week, at 8 a.m. We observed a 25% TSH decrease on the 4^{th} week of exposure. This change recovered fully one week after the end of exposure. In a second set of experiments, we looked at the spontaneous chronobiological rhythm of hormone secretion. The TSH decrease was not reproduced. There was no change in melatonin level, which is an hormone known to be sensitive to electromagnetic fields in rodents and avians. A significant change in cortisol remains to be further explored, as a 30 % GH decrease after the first drawing session may be attributed to an adaptation to experimental conditions.

Research on the nervous system:

As the auditory organ is the most exposed, we measured the auditory brainstem response before and after 1-hr exposure to mobile phones. No difference was observed.

Digital EEG was also performed, and showed significant differences which were not found in sham exposed volunteers. It seems that EEG is sensitive to mobile phone exposure, as was already published by Mann and Röshke [1], and by Thuroczy [2]. Further work is needed to define : i) the parameters important for this effect ii) the potential health impact of this effect.

These studies were funded by CNET (France Telecom) and by Motorola.

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Overview of the Findings from Motorola-Sponsored Health Effects Research

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For years, Motorola has had an extensive program of research on the potential interactive effects of radiofrequency (RF) energy. This initiative dates back more than two decades and reflects a long time commitment to science, standards and stewardship in assuring the safety of Motorola products. In recent years, this agenda has included a substantial program of extramural biological research carried out at eight institutions in the United States and Europe.

This bioresearch program comprises in vivo as well as in vitro studies, covering a variety of radio signals and modulation schemes (Analog, TDMA, GSM, CDMA, MiRS, iDEN and IRIDIUM). It has involved a number of experimental designs, including chronic and acute bioassays, and has been directed at a number of health-related biological endpoints, including tumor initiation or promotion, gene expression, hormonal secretion, DNA damage, DNA synthesis and cell proliferation More than 30 Motorola sponsored studies have been initiated, and 20 have so far been published in internationally recognized peer reviewed journals or presented at scientific meetings, including 13 in vitro, 6 in vivo and a human study. These studies have yielded no findings suggestive of adverse health effects from the use of wireless communications devices. The program currently has 7 major rat two year bioassay studies either ongoing or approaching completion. All involve exposures and radio signals characteristic of those associated with the use of wireless telephones.

Motorola advances additional RF bioresearch through its support of Wireless Technology Research L.L.C. (WTR) in the United States and Forschungsgemeinschaft Funk (FGF) in Germany. The Motorola research program also encompasses historical leadership in dosimetry and an ongoing large-scale epidemiological study of possible RF-related health effects among Motorola employees.

Biological effects of 900-MHz microwave exposure: the experience of the ENEA group

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At ENEA, several devices were built to expose biological samples, in collaboration with the Department of Electronic Engineering, La Sapienza, University of Rome. Various biological models were used :

a) ***In vitro.*** The immune system is a good target to study both the proliferation and the biological activity in cells in view of cancer-related effects. Cell lines of murine peritoneal macrophages (RAW 264.7) were used to evaluate the cytotoxicity in short-term experiments.

b) ***in vivo.*** We investigated the effects on the auditory system (otoacustic emission and cerebral metabolism), but only the results from the first assay are available. The modifications of DPOAE (distorsion products of otoemission) in rats exposed at 900 MHz (low SAR values of 0.2 -1.0 W/Kg).

Materials and Methods: A special TEM cell (120 cm, 11.5 cm, 11.5 cm) was developped for whole body animal exposure. It is set up as an expanded coaxial transmission line in which the center conductor is a flat metal strip (with plastic supports) and the outer conductor (ground) has a rectangular cross-section. Small biological subjects can be exposed to a pseudo plane-wave, with precisely known values of E and H fields. The other exposure system consist of a cubic volume built with materials that are minimally reflective, and a source operating at 900 MHz (double ridged waveguide horn antenna). The system was assayed previously with air tissue-equivalent phantoms using E-field probes.

a) In the first part of experimental program cells were exposed at power density of 1-2-4 W/m^2 for 1 hour with a dipole antenna and then, at power density of 5-10-20 W/m^2 for 2 hours. Viability was assayed using the Trypan Blue method, count cell with an emocitometer and phagocytosis by fluorescent microscopy of latex fluorescent particles.

b) In *in vivo* experiments, 64 adult male Sprague Dawley rats were exposed 900Mhz microwaves for 3 subsequent days, 4 h/d; while 32 rats were sham-exposed in a TEM cell (average SAR of whole body measurements and values of peak in the head were calculated); then 42 rats were sham-exposed, exposed at 900 Mhz with a SAR of 0.2 or 1 W/Kg, for 3 hour/day for 3 days. The rats, placed in Plexiglas tubes, were positioned 65 cm away from the source in the anechoic chamber. DPOAE were measured before and after exposure at 0, 24 and 48 hours in all animals of under general anaesthesia for both experiments.

Results: a) Preliminary results showed that there were no differences in growth, vitality and phagocytosis between sham and exposed cells at power density of 1-2-4 W/m^2. At higher power (5-10-20 W/m^2) no differences were found in the vitality and phagocytosis. A decrease in the growth of 30% was noticed in cells exposed at 20 W/m^2, 24 hours after exposure, but with a total recovery 48 hours later. **b)** There was not significative modification in chamber temperature and in body temperature due to exposure. DPOAE recordings were similar in all groups before and after exposure, although a large coefficient of variation was found among subsequent recording sessions.

Conclusions: a) Further experiments are necessary to confirm these data. b) The results are not suggestive of an effect of 900 MHz exposure on DPOAE in the rat cochlea. Therefore, we have to consider that there is a strong difference between isolated cells or tissue exposure and *in vivo* exposure effects; in this latter case there is a masking effect due to the overlaying structure and to the active homeostatic mechanisms that are able to react to every perturbation whether thermic or nonthermic.

SAR Distribution into Homogeneous and not Homogeneous Phantoms and into an Anatomical Model of the Human Head Generated by Cellular Phones

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The aim of this work is the numerical evaluation of the Specific Absorption Rate (SAR) generated by cellular phones into different models of the human head in order to evaluate what are the differences connected to the different methods to represent the head.

The analysis of the problem can be subdivided in three main parts. The first part is the phone representation. We have developed a pre-processing tool that prepares data for the electromagnetic solver in order to represent the cellular phones in their real conformation and to place them in contact to the head as requested by CENELEC Secretariat SC211/B WGMTE February 1997.

The second part is the electromagnetic solver, FDTD in our case, that must be able to analyse complicate configurations and must be validated experimentally on real cases.

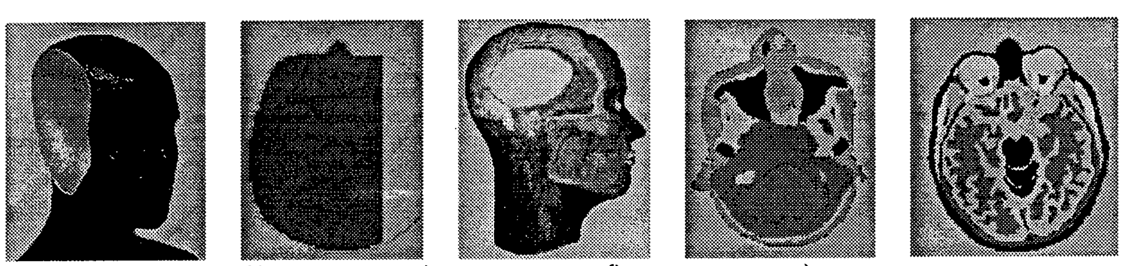
The third part is the definition of the models of the head. In this contribution we take into account two types of anthropomorphic phantoms and an anatomical model of the human head. The first one, named homogeneous, is constituted by a fibreglass shell having the human head shape, filled with a liquid simulating the brain, with an aperture on a side. In figure 1a) and 1b) it is represented the phantom and a layer of the numerical model. This phantom is used in a SAR measurement system and the aperture on the head's side permits to move an electric field probe into the phantom.

The second phantom we consider is a not homogeneous phantom constituted by 5 tissues (skin, muscle, bone, eye and liquid brain); figure 1c) and 1d) represent the phantom and a layer of the numerical model. The phantom has an aperture on the head side in order to perform measurements. The geometry of these phantoms have been obtained by means of a Magnetic Resonance (MR) system and each tissue have been labelled in order to describe the their geometry in the electromagnetic solver.

The anatomical model of the human head has been obtained by using a MR system and by using a recognising tool (based on neural networks) in order to give a label to each tissue; figure 1e) shows a layer of the anatomical model.

The electromagnetic solver has been validated, by measurements, with the homogeneous phantom radiated both by a dipole and by cellular phones while we will proceed for the validation of the solver on the not homogeneous phantom.

We will compute the electromagnetic field into the two phantoms and into the anatomical model of the head for different types of cellular phones in order to compare the SAR distributions, the peak SAR and the SAR values averaged on 10 g and on 1 g.



a) b) c) d) e)

Figure 1 :

a) Homogeneous phantom ;
b) A layer of the numerical model of the homogeneous phantom ;
c) Not homogeneous phantom ;
d) A layer of the numerical model of the not homogeneous phantom ;
e) A layer of the anatomical model of the human head.

Session M02
Tuesday, July 14, AM 08:40-11:40
Room R03
Near Field 1 : from Microwaves to Optics
Workshop on Complex Media and Measurement Techniques

Organisers : J. Ch. Bolomey, J. J. Greffet

Chair : H. Cory

What is the Signal Measured by a Scanning Near-Field Optical Microscope ?

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We adress the problem of the image formation with scanning near-field optical microscopes (SNOM). For the first time, a closed-form expression of the link between the detected signal and the structure of the sample (topography and optical properties) is given.

Strating with the reciprocity theorem for electromagnetic vector fields, we derive an *exact* (self-consistent) expression of the signal, and show that it is related to the polarization density in the sample. Our approach applies to the three main categories of SNOM, i.e., illumination-mode, collection-mode and apertureless set-ups. The result sows the polarization effect in the illumination/detection process. Moreover, it confirms that characterizing the probe is a crucial point in the analysis of the images.

Finally, using a single scattering approximation in the previous result, we show that the concept of impulse response (or transfer function) aries naturally. This gives a rigorous basis to the existence of transfer functions in near-field optics, when multiple scattering between the tip and the sample is negligible. Under this condition, an analytic expression of the transfer function is given, showing that the measured signal is not, in general, thesquare modulus of the electric near field.

The Nonresonant Perturvation Technique for Measurement of Electromagnetic Fields at Radio and Microwave Frequencies

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A very wide range of radio-frequency and microwave devices and systems operate by exchange of power between a region of electric field and charges, material, or radiation in that field. For the power transfer process to be properly understood, the field distribution throughout the region of the coupling process and its relation to the power transfer need to be known.

Examples of such systems are antennas operating at ultra-high and microwave frequencies used to couple electromagnectic power into body tissues for hyperthermia induction, or to couple power from tissues for radiometric temperature measurement. The relative importance of the parts of the tissue volume which are coupled to an antenna, for heating or for generating a radiometric signal, is determined by both the tissue dielectric properties and geometry, and by the spatial distribution of the antenna electric field. Proper knowledge of the field in the tissue is essential if adequate but not dangerous levels of tissue heating are to be achieved in hyperthermia therapy, and, similarly, the antenna response to tissue fields must be known if measured radiometric temperatures are to be related to actual tissue temperatures.

In the nonresonant perturbation technique a small dielectric or conducting body is moved through the electromagnetic field of the test device or system. The presence of this field perturbing body changes the stored energy in the field, and the power dissipation from the field, in direct relationship to the energy density and dissipation density in the unperturbed field. These changes are respectively equivalent to changes in the reactive and resistive parts of the impedance at the device or system excitation port, and can be measured as changes in the port relection coefficient. The absolute relationship can be expressed exactly in the form of an integral over the perturbing body volume of the unperturbed and perturbed electric and magnetic fields and the relative electromagnetic properties of the perturber and the medium it is immersed in. Further, if a spherical perturber is used, the symmetry rmoves any dependence on the field direction, an extremely useful feature of the technique not available to any other method.

Measurements in regions of known fields, such as plain waveguide, have verified the theoretical basis of the technique and have shown that practical implementations of the method can gie very accurate results. The technique has been applied to systems as diverse as particle accelerator structures, VHF probes for tissue dielectric measurements, and biomedical microwave radiometry simulations. Illustrative results from recent studies of biomedical antenna and coupled tissue region behaviour are presented.

Near-field Experimental and Theoretical Studies of the Optical Signal of a Half Conductor Plane Obtained with an Apertureless Probe

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Measures of the optical properties of samples with a resolution better than 20nm have been achieved since the introduction of Scanning Near-Field Optical Microscopy (SNOM)[1]. Now a strong effort is made to explain the behavior of this SNOM images[2]. The particularity of our microscope is the wholly metallic apertureless tip we use as a probe of the near-field optical signal [3,4]. The behavior of our first images of a half conductor plane obtained in the visible transmission-mode domain were very different from what we expected from previous reflection mode experiment[3]. This is the main raison of the models of the SNOM signal we have developed.

Our probe vibrates above an illuminated sample. It scatters periodically the electromagnetic field near the sample surface and radiates in the far field. A lock-in detection of the collected light at the tip vibration frequency allows us to detect the near-field optical signal locally scattered. This near-field optical signal, also called SNOM signal, has the optical resolution of the tip's end as was demonstrated in previous papers[3,4].

The sample we have studied is a step of 50 nanometers of Chromium on a quartz substrate. To model the behavior of the near-field optical signal, we have developed an analytical model based on the expression obtained by Van Bladel[5] where the metallic step is a semi infinite metallic plane and where we assume that the tip is a passive probe of the near-field signal. When the polarization of the incident light is perpendicular to the chromium step, we observe an enhancement of the optical signal on the quartz substrate close to the chromium step. This result is very different from what expected by comparison with the result obtained in reflection-mode by Bachelot et al [3] on the same sample. Nevertheless the optical signal of our theoretical analysis has the same behavior as the experimental signal near the metallic discontinuity.

This results have confirmed that the probe is almost passive in our experimental technique as it was expected in previous theoretical studies[6]. We are trying now to understand the way the metallic tip probes the near-field optical signal and scatters it in the far field. Our first analytical results for a reflection-mode set-up are very promising.

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Some Recent Developments in the Theoretical Investigation of Near-Field Optical Microscopy

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With a resolution far beyond the diffraction limit, scanning near field optical microscopy (SNOB) provides an extremely interesting way of investigating the interaction of electromagnetic fields with a broad range of systems ranging from microfabricated nanostructures to biological samples.

The key phenomenon towards achieving such a high resolution is the confinement of light by subwavelength scatteres. In this talk we investigate different schemes for achieving this confinement of light.

We first study the confinement by small structures deposited on a surface and evidence the relation between the structure shape and the topology of the near field spawned by that structure. For given illumination and observation parameters, the near field can perfectly reproduce the form of the structure, thereby enabling its high resolution imaging.

We then show that strong confined optical fields can also be created at the apex of a local probe microscope tip under external illumination. Several experimental parameters are investigated and the precise and continuous control of the field is demonstrated. Operative implications of such intense optical fields are also investigated.

Finally, we study the confinement of light at the aperture of a tapered coated optical fiber. Such a tip commonly used for imaging with SNOM and a detailed understanding of the behavior of the electromagnetic field as it travels trough the tapered region of the fiber is most important for interpreting experimental data and optimizing throughput of experimental setups. Again evanescent fields localized at the vicinity of the aperture play a key role for the overall resolution of such a microscope. We also investigate the back-coupling of the scattered field into the tip and the image formation mechanisms in a complete experimental configuration where both illumination and detection occur trough the same tip.

Signals Reconstruction from Their Square Complex Distributions

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The non linear inverse problem of reconstructing a complex signal from the knowledge of its complex squared values has interest not only from a theoretical point of view, but also in several actual situations. This problem, also referred in literature in the case of real valued signals as the *autoconvolution* problem [1], arises in stochastics [2], in spettroscopy [3], or whenever measurements of bandpass signals are acquired in monostatic set-up configurations, so that the corresponding square complex values of the signals are available [4-5].

The intrinsic difficulties of the problem of determining a signal from its square distribution can be appreciated by considering, f.i., a real signal, say $s_r(.)$, for which one wants to distinguish between intervals where it assumes positive and negative values. Indeed, since $s_r^2(\cdot)$ is positive even if the zero crossing points are carefully located, arbitrary sign can be given to each interval between two of such points, so that the problem admits multiple solutions. Moreover, in presence of additive noise, which corrupts data especially at very low levels, the task of singling out the zero crossing points becomes very difficult, because their position can not be determined with precision. In the general case of a complex signal $s(.) = s_r(.) + js_i(.)$, these simple reasonings can not be applied. The real and the imaginary parts of $s(.)$ are now coupled in the real and the imaginary part of $s^2(.)=\left[s_r^2(.)-s_i^2(.)\right]+j2s_r(.)s_i(.)$, and zero crossings of this latters are not directly connected with the signal to be reconstructed.

Direct solution procedures (i. e., analytical formal inversions) are not viable, also because in presence of errors on the data they are not stable, so that iterative algorithms, based on the minimization of proper functionals have to be used. To this end, and to correctly discretize the problem, data and unknowns of the problem, and the finite dimensional functional spaces which they belong to, have to be properly chosen. The knowledge of some analytical properties of the unknown signal, derived from its physical nature, can conveniently restrict the set of unknowns, restoring the possibility of finding the solution. A possible way to do that is to impose, where it is possible, continuity and regularity constraints on the signal under investigation.

The choice of the signal itself as unknown leads to the formulation of a quadratic inverse problem [5], allowing to deeply discuss the occurrence of false solutions (the local minima of the non-quadratic functional to be minimiezed), and to propose strategies to avoid them.

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On the Concept of Phase in Near-Field Optics

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Recently, phase imaging in the near field has received increasing attention, with direct measurements in the microwave regime [1,2], and the development of interferometric techniques in the visible domain [3]. Phase conjugation of optical near fields has also been demonstrated, together with the possibility of recording near-field holograms [4]. These new experiments have motivated some theoretical studies of the phase properties in the near field [5,6]

We present a theoretical and numerical study of the phase of the near field scattered by nanometric structures. Strong polarization effects and phase confinement is demonstrated, and explained by a model also provides a relationship between the phase and both the topography and optical properties of the sample.

Similarities with amplitude imaging are also discussed, with special emphasis on the spatial filtering. this issue of interest in the context of sub-wavelength resolution, since it has been argued that the phase could yield super-resolution even in far field [7], an argument in contradiction with subsequent analyses [1]. In fact, the concept of cut-off frequency leading to the diffraction limit applies to complex amplitude of the field, and thus to both its amplitude and phase.

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Analysis of Nonlinearly Loaded Antennas

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Two methods are presented for the analysis of nonlinearly loaded antennas. If the nonlinearity is mild, then a volterra series approach can be utilized for the analysis of nonlinear structure. The advantage of the volterra series approach is that the classical linear analysis techniques can be used for the solution of the nonlinear problem. Here the nonlinearity is made to appear as an excitation to a linear network. This results is a closed form expression for evaluating the response at an intermodulation product. Because the results are in closed form an accurate estimate of the various intermodulation products can be obtained particularly if the intermodulation products are lower than 70 dB. However, the number of terms of the series increases with the nature of the nonlinearity. If the nonlinearity is hard then a Green's function approach can be utilized in which the linear portion of the problem can be solved in the frequency domain. From these results one can extract the time domain Thevenin's equivalent network for the linear portion of the system. Then the nonlinear network associated with the linear portion of the network can be solved for utilizing a time domain technique. However, in order to obtain the frequency domain response one has to take the FFT of the data. This may mark the weak signals if they are located near the stronger signals due to the windowing effect of the FFT. So both the techniques has both positive and negative aspects. Depending on the type of nonlinearity each of the method can be applied.

Sampling criteria for low frequency Near-Field techniques

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Near-field techniques constitute a very attractive tool to characterize radiating systems. These techniques are essentially used actually for determining the radiated far-field of directive antennas at high frequency. However, the extension of these techniques to others application domains are worth considering. Especially near-field techniques should be a very convenient approach to obtain the far-field of low frequency (>30 MHz) antennas with indoor experimental setups.

As well known, near-field techniques consist 1) to measure the field very close to the antenna on a surface and 2) to calculate the field everywhere outside the surface of measurement. Generally, the field calculation is based on a modal expansion in specific coordinates system (planar, cylindrical or spherical). The coefficients of this expansion are derived from the near-field data on a coordinate surface. The surface of measurement is covered by scanning the probe on circles (angular variables) and/or linear lines (linear variables). Typically, the standard sampling requirements for antenna testing are for high frequency is $\delta\phi = \lambda/(ea)$ (radian) for angular variable and $\delta x = \lambda/2$ for linear variable, λ being the operating wavelength, and thea: radius of the minimal cylinder (or sphere) containing the antenna under test.

Using near-field techniques at low frequency introduces some new problems. First of all, the reflectivity of the absorber materials is higher. Secondly, the distance of measurement is smaller in comparison with the wavelength: consequently, the near field distribution involves evanescent waves and it is necessary to use a smaller sampling steps than for usual near-field measurements. This paper deals with these two aspects. To determine the required sampling step, numerical simulations on a small electrical dipole have been used. The radiated field is analytically known, at any distance and angle. The tangential and normal components of the electrical near-field can be calculated, on a linear axis and a circle, for different arrangements of the dipole with respect to the surface of measurement. The near-field calculation is performed on the measurement line with a very small step and its spectrum is calculated by Fourier transform on a very large spectral domain. The study of the spectrum level as a function of the spectral variable allows to determine the sampling step for a given error level due to spectrum recovering. For an example the near-field measurement on a linear axis located at a distance of $\lambda/8$ of a small dipole requires a sampling step of $\lambda/16$ to obtain 45dB dynamic range on the spectrum. In the case of the measurement on a $\lambda/2$ radius circle with same distance and dynamic range as the precedent example the necessary sampling step is 6°. This study gives the required step for a given configuration and the corresponding level of error on the near-field. The effects of parasitic reflections on the absorber materials have been also analysed.

Acknowledgment: This work was supported by CNES under grant n°962/93/CNES/0895/00

Session A03
Tuesday, July 14, PM 13:40-17:00
Room 300
Scattering and Diffraction of Electromagnetic Waves

Organiser : S.-Y. Kim

Chairs : S.-Y. Kim, S. Nam

Efficient Representation of the Rectangular Waveguide and Cavity Green's Function

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This paper presents efficient calculation methods of the potential Green's function in the rectangular waveguides and cavities using the Ewald sum transformation technique.

The Green's functions for the rectangular waveguides and cavities are notorious for their slow convergence, especially when the source and the observation points get closer to each other. This a major problem in the integral equation - moment method(IE-MoM) applications involving these structures, where the slow convergence of the Green's function severely degrades the efficiency of the overall numerical analysis. Therefore, special acceleration techniques are generally required to enhance the convergence of the Green's function series.

The slow convergence of the rectangular waveguides and cavities are closely related to that of the periodic Green's function. The periodic Green's functions can be represented by two different forms, the spectral domain modal expansion and the spatial domain image expansion. In general, both of these two forms have convergence problems and most of the techniques developed for the rapid calculation of the periodic Green's functions employ hybrid methods combining the spectral and the spatial domain calculations. The Ewald sum technique is one of such methods and can convert the slowly convergent periodic Green's functions into rapidly convergent forms using the error function transformation[1,2].

Upon the application of the Ewald sum technique, the Green's functions for the waveguide and cavity problems are converted into the sum of the spatial and the spectral domain series. The spatial and the spectral series take the form of the spatial domain and the spectral domain Green's function with each term of the series weighted by the rapidly decaying factors. The spatial domain Green's function for the rectangular waveguides and cavities are expanded in terms of images produced by the conducting walls, which forms the spatial series part after the Ewald sum transformation with each images weighted by the complementary error function. In the spectral domain, the Green's functions can be expanded by the modal functions of the waveguides and cavities. In the Ewald sum method, these spectral domain Green's functions constitute the spectral series with each modal terms weighted by the complementary error function(waveguides) and the exponential function(cavities). Therefore, both the spectral and the spatial series in the Ewald sum methods are rapidly convergent.

The transformed results by the Ewald sum technique are further simplified to reduce the computational amount, and specialized methods are developed for the effective numerical evaluation of the Green's function transformed by the Ewald sum technique. Numerical experiment shows that the proposed method can calculate the Green's function quite accurately with only small number of terms in the transformed series.

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Classification of Airplane-like Targets Using Scattering Centers and RBF Network

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In this paper, three airplane-like targets measured in a compact range are classified through the two steps of the feature extraction stage and the classifier stage. Since the three targets considered here have very similar geometrical shapes, classifying these targets from radar return signals is a quite challenging problem. To solve this problem, scattering centers and RBF network are used for the feature extraction stage and the classifier stage respectively.

For the feature extraction stage, the locations and amplitudes of scattering centers of these targets are extracted by three different one-dimensional signal processing techniques. Then, the obtained feature vectors(scattering centers) at several aspect angles are pre-processed according to the first and second order statistics of the entire training data set in order to improve classification performance. Scattering centers are directly related to the geometry of the target and their dimensions are very small in comparison with those of other features such as frequency-domain RCS data, range profile, SAR images and ISAR images, etc. This small dimensionality can reduce the computational cost significantly in the Automatic Target Recognition(ATR) system.

For the classifier stage, the RBF neural network is applied. The hybrid learning algorithm cosisting of supervised learning and unsupervised learning is used to train the RBF classifier and the leave-one-out method is used to estimate the probability of correct classification. Neural network classifiers are more appropriate for the real-ATR system than traditional decision-theoretic methods such as the nearest-neighbor and maximum likelihood. Although there are many neural network paradigms which can be used for classification, the RBF network is the most attractive since it has many computational advantages in terms of network learning and structure.

Classification results have demonstrated that the scattering center-based classification can achieve high recognition performance even for very similar targets. Also, it is verified that the robustness of the feature extraction stage and the accuracies of the extracted features are essential for the improvement of the classfication performance. This preliminary research has shown that scattering centers are very promising feature vectors which can be used in the design of a future ATR system.

Effects of Observation Distance Change on the Diffraction Pattern by a Cylindrical Air Cavity

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In locating high-contrast geological anomalies such as underground cavity, the geotomography scheme is limited since the refraction and the diffraction by a cavity are far beyond the correction level. A cross-borehole continuous wave electromagnetic probing is advantageous and effective method because its single frequency scheme gives greater dynamic range and is not affected by the host medium dispersion. If the signal wavelength in the host medium is comparable to the size of the air cavity, double dips in the amplitude pattern of the received signal occur at two locations corresponding to the top and the bottom boundaries of the cavity. The signal frequency providing the strongest double dips as well as the signal drop pattern highly depend on the distance of the measurement plane from the cavity.

The diffraction patterns of the total field scattered by the cylindrical cavity are theoretically analyzed. The amplitude dips of the total field occur at the points where the amplitudes of the scattered field are slightly different from those of the incident field. In the near-field region, these dips become nulls for certain signal frequency where the scattered field is equal to the incident field with its phase reverse, and the phase of the total field jumps 180° at the null point and varies less than 180° but abruptly about the dip point. At a fixed observation plane, the signal frequencies giving null pattern are obtained by plotting the equal-amplitude point, at which the incident and the scattered field have equal amplitudes, and the out-of-phase point vs. the signal frequencies. The signal frequencies providing the most significant signal drops and the corresponding dip positions are calculated as the observation distance changes. There are four types of the most significant signal drop patterns including double dips, double nulls, single null, and single dip. For various observation distances, the types of the strong signal drops and the corresponding signal frequencies are explicitly presented. The theoretical analysis for the interdependence of the signal frequency, the observation distance, and the diffraction pattern provides an effective tool to locate high contrast anomalies.

A Spectral Domain Wavelet Analysis of Scattering

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The moment method(MM) efficiently solves the scattering problem of an electrically smaller body. With a larger scatterer, the MM requires more computing time. In this case, the high-frequency methods like geometrical optics(GO) fastly solve the problem, but provide approximated solutions. Neither of the MM and the GO simultaneously obtains the exactness of solutions and the fastness in computation. In this paper, we present a spectral domain wavelet analysis method which is computationally fast without sacrificing the exactness .In an MM application, the characteristics of its impedance matrix(a system of the equations produced by the basis expansion and testing) determine the overall computing time. The impedance matrix can be recognized as a discrete form of the Green's function for the MM, and its efficiency in computation depends on the choice of basis functions. In this sense, it is important to know what kind of set of basis functions exactly represents the Green's function, and makes a very sparse matrix. As represented in the joint spatial-spectral domain uniquely developed by us, the spectral-domain wavelet bases are found to be proper to discretize it. As an example, the numerical solution of the scattering by a strip is introduced. Through this example, we will show the relationships between the wavelet transform method, the GO, and the MM. We suggest that the wavelet transform method can be used to study the MM and the GO as its extreme cases.

An Iterative Inverse Scattering of a High Contrast and Large Size Object by Using the FEM-LM and Prior Knowledge of Back Ground Medium

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An iterative inverse scattering technique (IIST) for a dielectric scatterer has been extensively researched with the nonlinear least square optimization based on the gradient algorithm. This IIST can be formulated as a problem to find -among a potentially very large number of solutions- a permittivity profiles solution with minimal cost[1]. For high-contrast object, the gradient algorithm such as the Levenverg-Marquardt algorithm(LM) may not give the original profile, because it converges to the local minimum values of the cost function, where the cost function is defined as the summation of the squared magnitude of the difference between the measured scattered fields and the scattered fields calculated by the method of moment(MOM). Pichot et al. [2] suggested that the high contrast object may be reconstructed by applying the simulated annealing (SA) algorithm, which may theoretically lead to the global minimum of the cost function, to the optimized inversion problem. Unfortunately method [2] suffers from the fact that the SA consumes excessive computation time in converging to the desired permittivity profiles. Park et al. [3] also suggested a more efficient hybrid IIST, combining SA and LM, than IIST using SA. However this hybrid IIST still suffers from the bottle-neck of SA in computation time. For large scatterer, the IIST using MOM also seriously suffers from consuming the excessive computation time in obtaining the converged permittivity distribution since MOM requires $O(N^3)$ floating-point operations in obtaining the solution of the scattered fields if Gaussian elimination is used to invert the N by N matrix.

Hence, in order for the IIST to efficiently reconstruct the permittivity distribution of a high-contrast and large-size object, the IIST requires two algorithms; one is a fast algorithm for solving the scattered fields and the other is an optimized algorithm which converges fast to the global minimum. In this paper, we use FEM for solving the scattered fields instead of MOM. We also use LM and prior knowledge of back ground medium to achieve fast convergence to the global minimum. First, one may obtain via LM the temporally reconstructed permittivity profile (TRPP), which consist of a target region and a partial region of back ground. The TRPP is one of the local minima. Since we know the profile of the background, we may modify the TRPP by substituting the profiles corresponding only to the background with the background medium. In the second iterative step, we use the modified profile as an initial value in order to get out of this local minimum of the cost function. The same procedures are repeated several times until IIST reaches the global minimum.

A square cylinder of size $1.6\lambda\times1.6\lambda$ divided into 106 cells is reconstructed by using the FEM-LM algorithm and prior knowledge of a back ground medium with 8 incident plane waves and 36 scattered fields taken on the circle of radius, ρ=2.0λ, at equal spacing. The square cylinder has been assumed to be an inhomogeneous two-layered dielectric scatterer, with ε_r = 5.0 and 3.0 from outer to inner layer. It will be numerically shown that our method give a good results of dielectric profiles mentioned above, in contrast the IIST without using prior knowledge of background medium does not give a good results due to being trapped in one of local minima.

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Diffraction Coefficients of a Composite Wedge Consisting of Perfect Conductor and Lossless Dielectric

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The geometrical theory of diffraction(GTD) has been played a leading role in analysis of high-frequency electromagnetic diffraction by conducting structures. But its extension to diffraction by dielectric objects is hampered due to no rigorous diffraction coefficients of dielectric wedges and cones. In spite of its simple geometry, a rigorous solution to the diffraction coefficients of a composite wedge is not available to date. Booysen and Pistorius presented the heuristic GTD-type diffraction coefficients of a composite wedge, but their solution could not satisfy the edge condition at the tip of the composite wedge.

In this paper, the E-polarized diffraction by a composite wedge consisting of perfectly conducting and lossless dielectric materials is formulated into the dual integral equations. The physical optics solution is sum of the geometrical optics field and the edge-diffracted field, of which diffraction coefficients can be expressed in finite series of cotangent functions weighted by Fresnel's reflection coefficients. It must be expected that the physical optics solution cannot satisfy the boundary conditions at the wedge interfaces and the edge condition at the wedge tip.

To reduce the error posed in the physical optics solution, its diffraction coefficients are corrected as following two steps. First, the periodicity of its diffraction coefficients is changed from 2π into $2\pi\ \nu_E$, where ν_E is the minimum positive value satisfying the edge condition at the tip of the composite wedge. According to the dual integral equations, the exact diffraction coefficients become zero in the artificially complementary region, in which the material inside(outside) the wedge is replaced by that outside(inside) wedge. To satisfy such a null-field condition in the extended region, the angular range of the complementary wedge region is defined differently according to the components of the diffraction coefficients.

In spite of those simple closed-form expression, the corrected diffraction coefficients can be reduced the error posed in the physical optics solution drastically. A number of numerical simulations illustrate that the diffraction coefficients of the physical optics solution violate the boundary condition at the conducting interface significantly. In contrast, the corrected diffraction coefficients approach the exact solution to the diffraction of the corresponding perfectly conducting wedge monotonically as the relative dielectric constant of the dielectric part increases to infinite or decreases to 1. And the corrected diffraction coefficients approach zero in the artificially complementary region of the composite wedge in any case of the relative dielectric constant of the dielectric part.

Scattering Anomalies by a Periodic Strip Grating over a Grounded Dielectric Slab

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Electromagnetic scattering by reflection gratings such as rectangular groove grating, sinusoidal grating, and triangular grating has been widely studied with main interest centering on both the Bragg backscattering(blazing) and off-Bragg blazing phenomena. Recently, experimental have been reported showing that periodic strip grating under consideration can be used to simulate the effects of the rectangular groove(corrugation) grating. However, most previous research has been limited to the Bragg backscattering phenomena in which all the incident power is scattered back in the direction of incidence, even for both the case of a comparative study between these two geometries and for the rectangular groove geometry. Most recently, some studies have been made of the off-Bragg blazing phenomena, where the incident electromagnetic wave is scattered at angles other than the Bragg angle, in a rectangular groove grating. However, this is not the case for a periodic strip grating over a grounded dielectric. Hence further study of the electromagnetic scattering characteristics including the off-Bragg blazing by the present geometry is needed.

The aim of this article therefore, is to consider an analysis method for the scattering characteristics of the present geometry and , by use of the method, to examine Bragg and off-Bragg blazing phenomena occurring in the present geometry. In more detail, electromagnetic scattering problem in case of oblique incidence and arbitrary polarization as a general case of the usual TE and TM formulation are analysed by the spectral domain method combined with the sampling theorem. In parallel with this, guiding(leaky wave) problem is also analysed in order to understand more how the Bragg and off-Bragg angles are related to the main beam angles of leaky wave emanating from the present geometry.

Some numerical examples are shown for the surface current distributions on the strip conductor which are helpful as a criteria for two distinct types of Bragg blazing existing in the present geometry. TE off-Bragg blazing phenomena which has not been observed, up to now, in the previous popular reflection gratings such as ruled grating, holographic grating with sinusoidal profile, and symmetrical lamellar grating, is reported. Some discussions on the relationship between Bragg and off-Bragg angles and leaky wave radiation angles are given.

Electrostatic Potential Distribution through Multiple Rectangular Apertures in a Thick Conducting Plane

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The behavior of the electrostatic potential distribution through apertures in a conducting plane has been studied by many investigators. Recently, we have examined the potential distribution through a rectangular aperture in a conducting plane [1]. The purpose of the present paper is to investigate the potential distribution through multiple rectangular apertures in a thick conducting plane by extending the Fourier transform and the mode-matching technique as used in [1].

Consider multiple rectangular apertures (two-dimensional finite array) in a thick conducting plane which is at zero potential. Assume that a potential is normally-incident on multiple rectangular apertures from above. We represent the scattered potentials in terms of continuous and discrete modes. In order to determine the discrete modal coefficients, we use the boundary conditions on the apertures and a conducting plane. The Fourier transform and the mode-matching technique are utilized to obtain the simultaneous equations for the discrete modal coefficients. The simultaneous equations for the modal coefficients are represented in rapidly-convergent series which are amenable to numerical computations.

The numerical computations are performed to illustrate the behaviors of the potential distribution through multiple apertures. We check the convergence rate of our series solution and confirm that our solution gives accurate results. The potential distribution (or penetration) into multiple apertures is studied in terms of aperture shape, periodicity and thickness. It is also useful to introduce the concept of the electric polarizability and study its behavior. The characteristics of the electric polarizability are illustrated versus the thickness of the aperture. The presented theoretical study allows one to better understand the behavior of the electrostatic field penetration into multiple apertures often encountered in EMI/EMC problems.

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Multiple Scattering and Diffraction of X-RAY Gaussian Beam by many Atom Distributions

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The wavelength of electromagnetic waves changed over from microwave to visible light with the times for sixty years. So far, X-ray has been used in crystal optics and in medical field as a method of analysis. Recently, generating techniques of powerful X-ray such as SOR (Synchrotron Orbital Radiation) and super precision processing techniques in atomic level have progressed. For these reasons, new type X-ray optical devices have been studied and the field of new X-ray optics such as X-ray lithography, X-ray microscopy and X-ray laser has formed. However, there are no high efficiency devices in X-ray region with the property of high energy, high permeability and shorter wavelength. The analysis of scattering and reflection of X-ray from boundary surface of matter in atomic level becomes an important problem for study and development of X-ray devices such as efficient mirrors and fibers, and their estimation are needed.

So the purpose of this study is to develop X-ray optical devices based on analysis of X-ray scattering, using BEM (Boundary Element Method), on the assumption that the incident Gaussian Beam is into the boundary surface of an array of atoms. For fundamental study of multiple scattering by many atoms group of materials, two-dimensional electromagnetic boundary problems are investigated. The model of atoms is cylindrical. Although atoms have finite refractive index distributions for electric charge and X-ray, we considered each scatterer as perfect conductor and dielectrics. Until now, analysis for only a few cylinders is reported. In the present study, we considered up to eighty cylinders using calculations based on the BEM technique. It becomes possible to solve far and near field solution of scattering of X-ray with regard to incident vertical and oblique angle for about eighty cylinders array, and to discuss total reflection for gracing incident angle. X-ray characteristics of evanescent waves are shown.

In this study scattering analysis is carried out as a function of wavelength of X-rays, and parameters such as radius of atoms, distance between atoms, the number of atoms and the number of layers. Then we repeated the calculations for various angle of incidence, in order to investigate the dependence of angle of incidence on the reflection and scattering characteristics, for optimum design of X-ray mirrors and fiber devices.

Session B03
Tuesday, July 14, PM 13:40-17:40
Room G/H
Electromagnetic inverse scattering problems

Organisers : Ch. Pichot, S. Caorsi
Chairs : Ch. Pichot, T. Habashy

One-Dimensional Profile Inversion Problems Related To Lossy Slabs Terminated By An Inhomogeneous Boundary

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An important class of the inverse scattering problems, which is very interesting from both theoretical and practical points of view, consists of one-dimensional profile inversion problems related to inhomogeneous lossy dielectric slabs. The aim in such a problem is to recover the permittivity as well as the conductivity of the slab by observing reflected and/or transmitted fields caused by a certain wave created in one or both regions separated by the slab. In these cases, the sources and observation points are located beyond the slab. Similar problems are also formulated in connection with quantum mechanics, geophysics, elastodynamics , acoustics etc. During the last three decades an extensive effort has been devoted to establishing effective exact, approximate and numerical techniques to solve these problems.

The aim of this paper is to consider the cases where it is not possible to locate the sources and observation points outside the slab. It is also assumed that , at one side of the slab, there is an inhomogeneous material boundary. The material boundary has a negligible thickness and can be characterized by an impedance, resistive or reactive boundary condition. The non-uniformity of the boundary affects the mathematical feature of the problem very seriously. The motivation for such a problem proceeds from the need of a quick exploration of the electromagnetic parameters of the atmosphere for military or rescue purposes. In this particular case, the inhomogeneous boundary will model the ground (supposed to be plane) composed of different parts such as forest, rocky soil, sea, etc. and makes the complementary half space inaccessible.

The method established here for solving such problems reduces the problem to the solution of two functional equations. Depending on the boundary, one of these equations is solved numerically or exactly. For example, if the boundary consists of a two-part impedance, the equation can be solved exactly by reducing it to a Riemann-Hilbert problem. The second equation is reduced under the Born approximation to a Fredholm equation of the first kind whose kernel involves the solution of the first equation. Since the latter constitutes an ill-posed problem, its regularized solution, in the sense of Tikhonov, is given. Illustrative examples show the accuracy and the applicability of the theory.

Inverse Scattering Problem for Stratified Anisotropic Medium

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We present an analytical approach to the inverse scattering problem of an anisotropic medium. The scattering problem is considered in the frequency domain, under illumination by plane time-harmonic electromagnetic waves. Assuming that the static magnetic field is parallel to z axis, the dielectric permittivity and magnetic permeability tensors varying continuously in z direction in the slab $0<z<L$ are taken as

$$\hat{\varepsilon}(z)=\begin{pmatrix} \varepsilon_1(z) & -i\varepsilon_2(z) & 0 \\ i\varepsilon_2(z) & \varepsilon_1(z) & 0 \\ 0 & 0 & \varepsilon_3(z) \end{pmatrix}, \qquad \hat{\mu}(z)=\begin{pmatrix} \mu_1(z) & -i\mu_2(z) & 0 \\ i\mu_2(z) & \mu_1(z) & 0 \\ 0 & 0 & \mu_3(z) \end{pmatrix}.$$

The goal is to reconstruct the constitutive parameters $\varepsilon_j(z)$ and $\mu_j(z)$, $j=1,2,3$, using the field measurements outside of the slab, or, equivalently, the scattering data. In terms of the propagating (along z axis) left- and right-going modes, Maxwell's equations are transformed into the 4×4 system of ordinary differential equations, suitable for solving the inverse scattering problem. Our approach to the inversion of the scattering data is based on the reformulation of the scattering problem as the matrix Riemann-Hilbert problem of a holomorphic factorization in the complex plane of the spectral parameter ω. The factored matrix is constructed from the scattering data for the real values of the spectral parameter, whereas the solution of the factorization problem is related to the certain solutions of Maxwell's equations.

We analyze the cases of normal and oblique incidence of illuminating waves, establish the uniqueness results and present the reconstruction algorithms. In the case of normal incidence, the 4×4 problem is decomposed into two 2×2 problems. The inverse problem is reduced essentially to the inverse scattering problem for the Zhakharov-Shabat-like system. The solution of the inverse problem is expressed in terms of the solution of coupled integral equations. The whole scattering matrix is determined by two scalar reflection coefficients that allows simultaneous reconstruction of two medium parameters. Influence of the parameter discontinuities at the interfaces $z=0$ and $z=L$ on the reconstruction procedure is discussed.

In the case of oblique nonnormal incidence, the simultaneous reconstruction of three medium parameters is performed by using the solution of the 4×4 matrix factorization problem. In general, the Riemann-Hilbert problem relates to the contour in ω-plane consisting of the real axis and the sufficiently large circle. Uniqueness and solvability of the factorization problem are discussed.

An Inverse and Optimization Time Domain Problem for a Stratified, Biperiodic and 2D Medium

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The aim of an inverse scattering electromagnetism problem is to determine physical properties of an object or configuration, from the known scattered near-fields or far fields.

In this paper, the involved parameters (permittivity and conductivity profile, impedance operator) should be reconstructed from the knowledge of time domain data (grating mode, reflection coefficient, far-field).

The problem is treated as an optimal control problem where the norm of the difference between measured and computed data is minimized, constrained to the state equation governing the system. The original constrained optimization problem is reduced to the stationnary point evaluation of an augmented functional, which is obtained by the method of "Lagrangian multipliers".

Profile reconstruction is carried out by a descent method (Quasi-Newton method).At each iteration, the state and adjoint state are solved by a Finite Difference Time Domain (FDTD) method. New estimates for the permittivity are obtained by a one dimensional search in a suitable descent direction.

In this paper, we show a generic optimization technique applied to various electromagnetic problems.

First, in 1D, we systematically study the models and analyze the measurements, as well as the parameters sensibility and regularization techniques. Therefore, "actual reconstructions" are available from the knowledge of impulsive data, after filtering and treating the frequential experimental measurements.

Then, periodic grating problems are studied, and an analysis of classical observation data (propagative eigenmodes) and of the number of observations data required is done. Therefore, reconstruction of dielectric and conductive inclusions for periodic gratings are simulated, and a grating shape optimization is presented.

Then the 2D problem is overviewed. The classical far field measurement data are specified and therefore the inverse problem goes on. Some results using parallel computers for the reconstruction of a double staircase profile and optimization of a dispersive absorbing material for aircraft show the good efficiency of the algorithm.

S.ALESTRA.
Problème inverse en Electromagnétisme dans le domaine temporel pour des milieux stratifiés, périodiques et bidimensionnels, Thèse de doctorat Université Paris XIII, 1997
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Inverse Scattering Using FDTD

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An investigation into the feasibility of using the Finite Difference Time Domain (FDTD) method for inverse scattering is presented. The motivation for the investigation has been to develop new techniques for improving the image quality of methods such as ultrasonic B-scan. Because ultrasonic B-scan is inherently time domain based it is thought that improvements based on FDTD would be able to be readily incorporated into existing B-scan algorithms. Enhancements of this kind improve the underlying model the inversion process is based and should be contrasted to post image processing approaches. Potential improvements include increased image resolution and reduced image distortion.

The approach used in this investigation is an iterative inversion procedure and it is assumed that time-domain backscatter data is available in a similar form to that used in ultrasound B-scan. To initialise the iterative procedure an image of the object is obtained by using conventional B-scan inversion procedures. FDTD is then applied to compute the backscatter data from this initial image of the object and the associated Frechet derivatives. Using these derivatives the problem is linearised so that inversion techniques like the Netwon-Kantorovich method can be used to provide an update of the initial image. These procedures are continued until the difference between the original and computed backscatter data are sufficiently small.

One of the major problems with using FDTD in this way to improve B-scan image quality is the potentially large computational overheads involved. To try and reduce the computational load, pixels are composed from groups of contiguous FDTD grid cells (with an associated tradeoff in resolution) and therefore the number of Frechet derivatives to be computed can be kept manageable. In addition by using causality, each Frechet derivative can be found by using a minimum of time-steps. Novel analytical methods for reducing the computational load in computing the Frechet derivatives may lead to even greater savings in the large computational load.

To demonstrate the effectiveness of the overall inversion algorithm preliminary results will be provided. To keep the computational load manageable two-dimensional geometry is considered only. A 256x256 FDTD grid space is employed in which a Gaussian plane wave pulse is used to probe the object. Backscatter data is utilised and pixel sizes from 10x10 to 50x50 grid samples are used. Convergence of the inversion procedure is investigated for a variety of shapes and refractive index distributions.

Our FDTD results are also compared to frequency domain based approaches such as the Born and Rytov approximations. Even though these approaches use different forms of the scattering data the comparisons do reveal some interesting trends.

Three Dimension Reconstructions Using a Time Reversal Matrix Method

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We use a numerical and temporal simulation method, the Transmission Line matrix Modeling (TLM) method, to study the electromagnetic field propagation. The infinite space is simulated using the Perfectly Matched Layers (PML) proposed by Berenger. By a time reversal development, an easy pattern recognition approach is proposed. The inverse crime is considered both in conducting and in dielectric structures.

Theoretical development

The TLM is a temporal and spatial iterative process which allows to obtain the temporal evolution of the six electromagnetic field components inside a network of interconnected transmission lines called TLM node. On each one and for each temporal iteration, we compute the reflected pulses using the S matrix applications from the incident pulses on these points in order to obtain, at the end of the simulation, the six temporal electromagnetic fields at the same location. The TLM is particularly suitable to take into account the finite dimensions of the studied structures. Using the Perfectly Matched Layers, we simulate the infinite space of propagation. With an input temporal pulse, we obtain the results in a very wide frequency band.

An important property of the TLM node is that its scattering matrix is equal to its inverse and this allows to use the same propagation algorithm to reverse the TLM process. Then, the inverse studies with TLM have been previously developed in two dimensions but using only the voltage impulses on the interconnected mesh of lines. We use the same approach but we use the fields, as in an electromagnetic inverse problem, instead of voltages to initiate the problem. We consider the 3D free space with a variable mesh and the new 3D-TLM node using the PML developed by Berenger. We propose reconstructions of various shapes of conducting elements such as a cube, a cross and a hollowed square. White noise is added, on each node, at each temporal iteration, to the signal before the time reversal in order to consider the inverse crime disagreement.

Results

With this new 3D-TLM-PML node, we note an improvement concerning the memory space needed, which makes the 3D-TLM inverse technique able to solve many problem. We show that the three dimensions obstacle, in a free space, is correctly reconstructed after only one inverse process. The temporal fields used allow a correct recognition of the various shapes studied.

We use many Signal to Noise ratios (S/N) to study the inverse crime. We have no problem with S/N=35 dB, and the reconstruction of the 3D object profiles can be made, even with S/N=5 dB, with a little damage using a PML parallel code.

Time Domain Modeling of Interferometric Measurements

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Imaging of surface topography using the Interferometric Synthetic Aperture Radar (IFSAR) measurement requires proper interpretation of the radar signal interaction with surface cover. The presence of penetrable surfaces such as vegetation, and tree canopies poses a challenge since the depth of penetration depends on a number of parameters such as the operating radar frequency, polarization, incident angle, as well as terrain structure. Multiple reflections of the radar signal creates additional complexity for interpretation of the derived topography from the IFSAR imaging systems.

In order to address the issues of the depth of penetration and multiple reflection, this talk presents a time domain method for simulation of the IFSAR measurements for complex environment. The imaged environment is composed of tree covered surfaces, where the tree structures and ground are modeled as dielectric material with loss. The objective of the simulation is to relate the derived IFSAR topography to the imaged environment parameters. The IFSAR simulation is carried out in two steps.

First, the forward scattering data is generated based on full wave analysis.

Next, the electromagnetic information is inverted to generate surface topography. This inversion is based on the well known IFSAR processing technique which is composed of signal compression, and formation of an interferogram. The full wave forward scattering data is generated by the scattered-field formulation of the FDTD algorithm. In order to limit the required computational resources, a 2-D model of the imaged environment is considered first. The issues of depth of penetration and multiple-scattering are well represented in this model. The simulation is carried out by exciting the computational domain by a radar signal. The scattered field is then computed and translated to the receiving interferometric antennas using the time-domain Huygen's principle.

The inversion process starts by compressing the time-domain data. The range compressed data from both receivers are then coregistered to form an interferogram. The resulting interferogram is then related to the ground topography using the radar imaging geometry. This methodology is extended to include three dimensional geometry of reduced spatial extent. In this presentation, a number of canonical topographies are considered, and the constructed topography is related to surface geometry, material properties, and frequency.

Reconstruction of Complex Permittivity Profiles of Maxwellian Scatterers by Means of Multiple Frequencies of Irradiation. A Finite Element - Sensitivity Analysis Technique

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In this paper the inversion of microwave imaging data for the reconstruction of complex permittivity profiles of maxwellian scatterers is treated using an iterative spatial domain technique. This technique that has been recently proposed by the authors is expanded for the case of irradiations that consist of different distinct frequencies.

In this work, we consider the reconstruction of the profile of an infinitely long cylindrical scatterer of arbitrary bounded cross-section that is characterized by inhomogeneous isotropic and nonmagnetic dispersive material properties. The dispersion relation of the inhomogeneity is assumed to be of maxwellian type. The scatterer is irradiated from a variety of angles of incidence by transverse magnetic plane waves and a number of different excitation frequencies is used. The inversion is based on the scattered far field measurements that are obtained at various positions around the scatterer domain.

The proposed technique is totally oriented to the differential formulation of the scattering problem and is a combination of the finite element method and a nonlinear conjugate gradient minimization method. Starting from an initial guess of the scatterer profile, the reconstruction technique updates iteratively the complex permittivity distribution of the scatterer. This is implemented by use of the Polak - Ribiere optimization algorithm which minimizes an appropriate cost function. The objective function takes into account all the excitation frequencies, being a measure of the distance between the known and the computed scattered field data that are obtained by use of the finite element method and the extinction theorem.

The application of the Polak - Ribiere algorithm requires the evaluation of the gradient of the cost function with respect to the scatterer profile. This is obtained by differentiating the system of equations of the finite element method. The computational burden of this sensitivity analysis approach is reduced by implementing the adjoint state variable methodology.

The proposed method is applied to a variety of cylindrical scatterer profiles.

Electrical Characterization of Materials by Solving an Inverse Problem Using the EMIR Method

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To realize non destructive testing on materials with defects, like radomes for example, we present an inverse method based on measurements obtained by the EMIR (ElectroMagnetic InfraRed) method.

In the EMIR method, the studied object is illuminated by an antenna located far away to simulate an incident plane wave. Photothermic films are used as sensors to measure, on a large grid of space points, values which are proportional to the magnitude of the scattered electrical fields.With the data available, we can formulate an inverse least-squares problem to evaluate the intrinsic permittivity and conductivity of each homogeneous part of the object.

In the problem, only the boundary of the object is defined but the location of the transition between homogeneous parts and the respective values of the permittivity and conductivity are unknown.

In this inverse problem, we have to minimize a least-squares problem where the cost function is the residual between the measured and the computed squared elcetrical field ; the unknowns are the intrinsic permittivity and conductivity. To solve numerically the inverse problem, we use a quasi-Newton method for the optimisation of the least-squares problem and a FDTD method to solve Maxwell's equations. This method allows for an easy computation of the scattered fields for dispersive complex 3D objects ; each cell of the object in the FDTD mesh has a constant permittivity and conductivity. In the optimisation process, the gradients are evaluated by a Broyden's formula. The advantage of this formula is to reduce the CPU time compare to a complete computation.

Several tests have been realised on small piecewise homogeneous samples with an edge size of a few centimeters, at a set of discrete frequencies in the range of 10 GHz to 12 GHz.
We present the intrinsic permittivity and conductivity values obtained by the solution of the inverse problem where the data are the EMIR measurements. We also give the CPU time, the selected initial values and the number of control points for all the cases studied.

Impedance Determination for the Optimization of Diffraction Patterns

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Our aim is to provide a method for the determination of charges localized on a diffractive body, so as to optimize the diffraction pattern. This kind of methods allows the design of antennas or can be apply to radar furtivity.

The first step consists in developping a reliable direct method. Here me make use of the Electric Field Integral Equation (EFIE). This equation is solved by means of a moment method. A linear system is then derived, under the form : ZI=V with Z : generalized impedance matrix, I : unknown surface currents, V : source term. The charge impedances only affect the main diagonal of z. Consequently, it will solely carry the variations during the optimization process.

The problem is then to derive an expression of the induced variation of the electric field by a variation of the impedances. The obvious expression ZZ-1=Id leads to d(Z-1) =-Z-1 d(Z)Z and then dE=-NZ-1d(Z)I. Besides, a cost function depending on E being chosen, the expression of dE allows an explicit calculation of the derivative of the cost function. The optimization process makes then use of a conjugate gradient algorithm.

Numerical results will be given for the optimization of various diffraction patterns.

Refractivity modeling for the inverse medium problem in tropospheric electromagnetic propagation

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Experimental results in the inverse problem of inferring the refractivity structure associated with the capping inversion of the marine atmospheric boundary layer (MABL) from measurements of beyond-line-of-sight propagation were reported by the author in 1997. A conventional approach to solving the inverse problem was utilized. A global optimization was performed to minimize the mismatch between measured and modeled electromagnetic (EM) fields. The modeled fields were generated using a refractivity model to map refractivity parameters (the capping inversion base height and the inversion strength) into a refractivity profile, and a propagation model to map the refractivity profile, path geometry, etc. into the EM field.

In the described work, a three-parameter "tri-linear" refractivity model was used. The tri-linear model appeared to be quite adequate when ducting was the dominant mode of propagation. When the contribution of scattering to beyond-line-of-sight signal levels was on the same order as, or greater than, the contribution from ducting though, the tri-linear model appeared to be a biased model.

An empirical model, based on the second order statistics of measured refractivity profiles is now developed. The Karhunen-Loeve (KL) transform is used to develop a set of empirical orthogonal functions (EOF's) from refractivity profiles that have been shifted so that the heights are referenced to the inversion base height. Using the KL transform, realizations of refractivity can be synthesized that are conditioned on the capping inversion base height and the inversion strength but whose fine structure is statistically similar to those found in measured refractivity profiles. The model is referred to as the shifted-EOF (SEOF) model.

The propagation estimation performance of the SEOF's conditioned on capping inversion base height and M-deficit derived from the soundings is compared to that of the associated soundings and tri-linear profiles. The utility of this form of modeling of refractivity is discussed, including application to the inverse medium problem.

Some Numerical Approaches to Solving the Inverse Problems of Electromagnetoelasticity

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The presentation will dedicated to the some numerical methods for thesolution of the inverse problems for the equations ofelectromagnetoelasticity.We consider the Maxwell and the Lame systems in the case whenelectromagnetic (EM) field is generated by elastic oscillations.At the same time, we neglect the reverse influence of the EM fieldon the elastic oscillations.

It is well known that when elastic waves are propagated through an electroconductive medium within the magnetic field, an interaction between EM and elastic oscillations appears. The resulting waves are called the electromagneto-elastic waves.

The influence of the EM field on the deformation field is considered as a result of the Lorentz forces arising in the equations of movements. To reflect an increase of the electric field density, an additional term should be included into the equation describing the Ohm law. This term is dependent on the velocity of particles which move in the magnetic field. In this case, the influence of the magneto-elastic field on the elastic waves propagation to be negligible. At the same time if the original magnetic field is strong enough, the influence of the magneto-elastic forces can be significant.

We consider the problems of determining some elastic and electromagnetic parameters of a layered medium from a weakly coupled linearized set of equations of electromagnetoelasticity. Results of numerical experiments will be given to illustrate the efficiency of the proposed methods.

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Session C03
Tuesday, July 14, PM 13:40-17:40
Room I
Advanced Techniques for Absorbing Boundaries in Computational Electromagnetics
Organiser : J. P. Berenger
Chairs : J. P. Berenger, F. Jecko

Generalized Theory of Perfectly Matched Layers in Curvilinear Coordinates

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With the advent of Berenger's theory of perfectly matched layers (PMLs) and its subsequent variations both in formalism and numerical implementation, numerical reflections from the grid truncation boundary in finite-difference time-domain (FD-TD) and finite element (FE) solutions of unbounded electromagnetic problems can be kept at levels low enough to facilitate numerical solutions of high accuracy. In most cases, successful use of PMLs for numerical grid truncation has been demonstrated on rectangular grids. More recently, extensions of the PML theory to cylindrical and spherical coordinates have been presented (Maloney, et al, *Proc. 13th ACES*, March 1997; Teixeira and Chew, *IEEE Microwave Guided Wave Lett.*, Sept. 1997). In addition, attempts have been made to apply PMLs to unstructured grids, and preliminary results from these efforts indicate that PMLs could, in principle, perform as well as in the case of orthogonal grids (Navarro, et al, *Electron. Lett.*, 1994; Roden and Gedney, *Microw. Opt. Tech. Lett.*, Feb. 1997).

In this paper, a systematic derivation of PMLs in curvilinear coordinates is presented. The development provides a generalization of previous efforts, and is aimed at the implementation of PMLs to the truncation of non-orthogonal, unstructured grids of the type required in the numerical modeling of waveguiding structures with non-rectangular cross-sections, as well as planar, three-dimensional waveguiding/radiating structures. The latter, often include non-rectangular conductor and material patterns which are most efficiently and accurately discretized using unstructured grids.

Another attribute of the proposed development is that it can be used to recover the special cases of PMLs in any orthogonal coordinate system in a straightforward fashion. Thus it provides for a generalization of previous efforts for developing PMLs on cylindrical and spherical grids.

Numerical results are presented from the implementation of the developed non-orthogonal-grid PMLs to the truncation of unstructured FDTD grids used for the transient simulation of electromagnetic radiation problems as well as the electromagnetic analysis of metallic waveguides of non-rectangular cross section and associated filter structures.

PML for Curvilinear Coordinates via Complex Coordinate System

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In this talk, we will discuss an alternative viewpoint of PML, originated by Berenger, using a complex coordinate system. The complex coordinate system allows us to systematically extend PML in Cartesian coordinates to other curvilinear coordinates, such as the cylindrical and spherical coordinates. It also permits the easy derivation of anisotropic media to model a PML medium in Cartesian and other curvilinear coordinates. Furthermore, the application of PML to other partial differential equations like acoustic and elastic wave equations becomes obvious. It is also obvious as to how the PML method can be applied to inhomogeneous media up to the edge of the simulation domain. For instance, then a half-space medium is truncated with a PML medium, it absorbs as well with no reflection in principle. One can simply map the partial differential equation to the complex coordinate space. In the case of Maxwell's equations, a systematic way of deriving the corresponding anisotropic medium formulation is demonstrated.

We will show the numerical implementation of the PML in cylindrical and spherical coordinates in the time domain using such concepts. We will further show that PML is stable when the surface that is coated with PML is concave, but PML is unstable when the surface thus coated is convex. We will provide an explanation for the observed phenomenon.

A new look to Berenger's Absorbing Boundary Conditions: Extension to 3D magnetic and dielectric anisotropic media*

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Berenger's Perfect Matching Layer (PML) Absorbing Boundary Conditions (ABCs) are treated from a different point of view which permits to extend its application to magnetic and dielectric anisotropic media. The numerical simulation of the propagation of waves in this type of media is a topic of current interest in connection with the design of microwave components, microstrip waveguides and fibre optics, and requires the truncation of the computational domain. In previous contributions, the authors have studied the extension of PML method for matching anisotropic media through the proposition of continuity conditions. Specific equations were found for the absorption of both the ordinary and extraordinary waves in a bidimensional, dielectric medium. The present communication describes a systematic procedure to obtain different versions of Berenger's PML for matching waves propagating in magnetic and/or dielectric anisotropic media. The well known 3D PML, established by Katz et al. and Berenger for isotropic media, and the PML for anisotropic ones recently proposed by Zhao et al., are obtained as special cases in a simple and straightforward manner.

The method uses matrix notation in order to generalize Maxwell's equations for dielectric and magnetic anisotropic media to define a computational Berenger type medium, with which perfect matching is achieved. In this extended PML (EPML) medium, six dimensional "split" fields are defined which obey a set of equations similar to Maxwell's ones for the real medium. Perfect matching is obtained at the interface between both media imposing the continuity of all the field components on the incident side with those of three-dimensional "compact" fields related to the split ones. The fulfillment of the above conditions, in such a way that waves incoming to the interface are absorbed, without any spurious reflection taking place at its edges and corners, leads to a set of linear relations between the constitutive parameters of the medium and those of the EPML. These relations show that there are different options for matching a given medium and devising an EPML. In the case of isotropic media, one of the options is Berenger's PML. With the same simplicity, suitable conditions for matching anisotropic media are obtained. An extension to adapt bi-anisotropic media is also proposed.

Although PML has been extensively validated, results obtained with the FDTD method are presented for the numerical reflection coefficient of an EPML matching dielectric and magnetic anisotropic and bi-anisotropic media.

* This work has been partially supported by the National Research Project TIC-96-1072-C04-01

Conductivity Profile Optimization for the PML ABC in FDFD

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The Perfectly Matched Layer (PML) proposed by Berenger (Berenger J. *Comp. Physics.*, 1994) is an extremely effective lattice termination condition in both time domain and frequency domain field computation. The ideal, continous specification of the PML can have arbitrary loss characteristics, which can absorb without reflection waves incident from any angle. In finite difference wave modeling, however, the staggered electric and magnetic field grids prevent the specification of the same medium at a given position forboth E-field and H-field, leading to numerical reflections. To minimize these reflections, the value of conductivity in each PML layer must be profiled so that it is smallest next to the free space/PML boundary, and rises for subsequent layers. The optimal specification of this profile is an open question of much interest tothe computational electromagnetic community.

Unlike the in time domain case (Gedney, *ACES* 1997, and Fang and Wu, *IEEE Micro. Guided Wave Let.* 1996), the FDFD formulation of a multilayer PML can be stated explicitly and exactly. One way of doing this is to use the discretized impedance of one layer relative to that of the subsequent layer to iteratively determine the impedance « lookin into » the PML at its boundary, relative to the PML termination. For normalized impedance of the *i-th* layer of width Δ, $\eta_i = \left(E_i / H_{i+\frac{1}{2}}\right)/\eta 0$, for a plane wave incident with angle θ on a planar layer boundary normal to $\hat{x}$, the recursive relation is :

$$\eta_i = jk\Delta\cos^2\theta + \frac{S_{i+\frac{1}{2}}}{2}\cos^2\theta + \frac{1}{jk\Delta + \left(S_{i-\frac{1}{2}} + S_i\right)/2 + 1/\eta_{i+1}}$$

where $k = \omega\sqrt{\mu \in}$ and $S_i = k\Delta\sigma_i/\omega\in_0$ (= $\sigma_i\eta_0\Delta$ when all PML layer dielectric constants are 1). Note that this formula allows the specification of conductivity values at every half layer, doubling the number of layer parameters from the original. Also, the effects of a tuned PML termination, given by η_{max} (Rappaport, *IEEE Trans. Mag.*, 1996) can be carefully examined.

To find the best conductivity coefficients for a wide range of angles and frequencies, numerical optimization is performed to minimize a cost function based on the error between the free-space transverse wave impedance, $\cos\theta e^{jk\Delta\cos\theta/2}$, and the impedance looking into the PML, η_1. The goal is to find a set of σ_i and in a trmination η_{max} that keeps the weighted error small for all frequencies of interest (0 to 75°, say) and all frequencies of interest. The solution to this problem also applies to the coefficients for the FDTD PML layer.

Perfectly Matched Layers in the Transmission Line Matrix (TLM) Method.

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We have developped a new symmetrical condensed node (SCN) for the implementation of the Berenger's Perfectly Matched Layers (PML) in TLM method[1]. This new SCN only needs to add 6 stubs to the standard SCN. Since it can simulate at once vaccuum and PML media, this new SCN can be used in all the computational domain leading then to a uniform TLM scheme. Neverthless, it can also be directly connected to the standard SCN. We propose here evaluations of the PML efficiency by giving comparisons between TLM and FDTD methods. We show that PML implemented with this modified node provides as good efficiency in TLM as in FD-TD method. We applied these developments by performing characterization of microstrip antennas using more reduced computational domain.

Comparisons between TLM and FDTD : We have studied the capability of the PML to absorb the electromagnetic field radiated by a dipole. Our results obtained with TLM are compared to those given by Berenger with FDTD[2]. Various parabolic and geometric conductivity profiles were considered. It appears that PML's behaviours are very similar in the time domain and in the frequency domain for the two methods. A critical study of the results of these comparisons will be given.

Characterization of microstrip antennas : In some previous studies [3], we have shown that the characterization of microstrip antennas can be achieved successfully with PML or Higdon's conditions using a computational domain of about 0.5λ surrounding the antenna. We have performed some simulations by reducing this computational domain to 0.2λ. With such configuration, four cells PML layers set only two cells from the radiated element still provide radiation pattern very close to those obtained with more extented computational domain.

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The Application of the Complementary Operators Theory to non-Analytic Boundary Conditions and Unstaggered FDTD Mesh

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The idea of using complementary operators to reduce non-physical reflections from the outer boundaries of the FDTD mesh has recently been made more practical by the introduction of the Concurrent Complementary Operators method (C-COM) [Ramahi, *IEEE Trans. Microwave & Guided Wave Lett.*, June, 1997]. In the C-COM implementation, the complementary operators are applied simultaneously in a single computer simulation, thus allowing for significant reduction in non-physical reflections arising from the side and corner regions. Encouraged by the performance of the C-COM in comparison to other mesh truncation techniques, we extend the construction of complementary operators to encompass numerical boundary conditions such as Liao's and other non-analytic boundary operators. This extension was found to be as effective as applying the complementary operators theory to Higdon type boundary conditions. In addition, we found that this extension is helpful in creating a better understanding of the instabilities that arise from the corner region whenever a boundary operator is introduced. Finally, we explore the application of the C-COM procedure to a recently introduced unstaggered FDTD scheme in curvilinear coordinates.

PML for Paraxial Electromagnetic Codes

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The recently developed vector parabolic equation (PE) technique [1] provides an efficient framework for bistatic RCS calculations of three-dimensional objects. The idea is that instead of treating all the points of the computational domain, the solution is marched though the domain plane by plane. The solution on the next plane can be obtained from the solution on the previous plane plus the corresponding boundary conditions on the object surface. On the outer boundaries of each plane (interception of the plane and the computational domain) an absorbing condition required.

An exact domain truncation technique exists for the parabolic equation [2], but its implementation is not straightforward in three-dimensional case. By contrast, the Perfectly Matched Layer can be easily adopted for the 3D vector PE method and is proven to be efficient. We are working in Cartesian coordinates, the computational domain is a rectangular box placed around the object. Each "slice" of the domain is a rectangle with a suitable PML placed around its boundaries. The parameters of the layer can be optimised as in [3]. We have used the Neumann condition to terminate the layer, which seems more efficient in this case than the Dirichlet condition. Results for 2D and 3D calculations will be presented.

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Implementation of the PML in the Parabolic Equation

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Numerous methods have been developed for the study of electromagnetic waves propagation on great distances (geometric optics, physical optics,...), particularly for wave propagation in the atmosphere. Their main drawback is the difficulty of dealing with refracting index variations along the ray paths. One of the best alternative is the Parabolic Equation which is a paraxial approximation of the Helmoltz equation. This method has proved its efficiency for applications such as the study of the propagation in complex tropospheric environment, low frequency propagation underwater for submarine communications and propagation in urban environment. In those kind of approaches, the validity is assumed in a privilegiate direction function of a choice of particular coefficients. The usual parabolic equation have limitation of angles around 15 degrees, another choice of the coefficients due to Claerbout allows good results to be obtained up to 45 degrees. In order to solve the parabolic equations, different approaches have been investigated, the implicit ones have proved to give stable and good results

The main problem in the Parabolic Equations approches is the free space representation. The purpose of this paper is to show that it is possible to use the PML technique as done by F. Collino in seismic problems [1]. In theory, the P.M.L. can absorb without reflexion the outgoing waves. But, in actual computation, an amount of numerical reflexion is observed. We have focused our attention to this numerical reflexion with the intention of designing an effective and optimized P.M.L. for the Parabolic Equation. This problem has been investigated by the theory of numerical reflexion and by numerical experiments. Some particular effects will be pointed out :

- A very thin layer of about one lambda is sufficient to make the reflexion coefficient lower than -40 dB when the P.M.L. absorption is well chosen. It can be shown that the theory of numerical reflexion can quickly give a very good idea of the P.M.L. reflexion coefficient in a certain range of conductivity.

- In some cases, the reflexion coefficient can be low for a special angle but can strongly increase outside this angle : in this case the reflexion coefficient results from the interference of two waves.

- The effect of the interface between the vacuum and the P.M.L. medium will be of a great importance in the behaviour of the reflection coefficient.

Reference

[1] F. Collino. Perfectly Matched Absorbing Layers for The Paraxial Equation. Journal of Computational Physics, 131, pp : 164-180 (1997)

Exact "Absorbing" Boundary Conditions for FDTD Algorithms in non Classic Domains.

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The problem of computational space limitation in FDTD approach for analyses of transient processes in infinite domains with compact resonant discontinuities is solved in mathematically correct way. The formulation the exact ABC and their inclusion in to computational scheme make up the basis for the approach that has to be presented. The ABC suggested herein constitutes parcial (in expansion over evolutionary basis [1]) radiation conditions or non stationary wave "departing" from the domain of efficient scatterers and sources location . These formulas represent by themselves separated exact radiation conditions for "outgoing" in given direction non stationary wave. These exact radiation conditions, related to the coordinate boundary in the waveguide cross section, or in virtual boundary surrounding effisient scatterers and sourses for open problem, are correctly incorporated into standard FDTD schema like ABC, without distortion of secondary field in zones of scattered by resonant discontinuities field.

Three schemes of such incorporation, optimizing the routine of output data, are developed and implemented.

It should be emphasized that these conditions do not take the original initial boundary-value problem and its discrete finite difference analogue out of the class of correctness. These conditions do not input any changes into the phenomenology of physical processes that are simulated. The modified "closed" problem is equivalent to the original "open" one.

The corresponding algorithms can be successfully used for transient processes analyzing the following 2D and 3D scalar and vector problems: compact scatterers, placed in free space or situated close to locally irregular boundary between two homogeneous media; resonant discontinuities in wave guiding lines and Flouque channels (periodic gratings).

Three schemes of such incorporation, optimizing the routine of output data, are developed and implemented.The testing numerical experiments that have been carried out provided exploiting characteristics of algorithms, showing their efficiency and reliability.

Comparative analyses of errors: global, calculated allover grid nodes, and local, received in single separate node, arising in FDTD schema with classic heuristic ABC, relying on various order of approximation, and with suggested exact ABC of the numerical solution of test problem have been carried out. Such study gave following results: The error of the schema, suggested herein is steady and coincides with the error reasoned by the finite difference approximation of original initial boundary value problem while its discretization. The algorithms with classic ABC, as it is well known, gives considerably larger errors, and that is essential, the errors values are unpredictable and rather sensitive to subtle structure of transient field near virtual boundaries. This is of special importance for wave scattering problems in parameters' region when resonant phenomena may occur.

The result of these and others numerical experiments, that are oriented to the testing of new exact ABC have to be presented and discussed in the report.

Reference

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A comparative study of the PML Absorbing Boundary Condition and the Higher-Order Absorbing Boundary Condition

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Structures to be analysed and designed by Finite-Difference Time-Domain (FD-TD) method are theoretical defined in an open region. As no computer can store an unlimited amount of data the computational domain has to be limited in size. Therefore boundary conditions are applied in order to simulate wave propagation out of the computational domain without any artifical reflections. In recent years, the Higher-Order Absorbing Boundary Conditions (HABC) and the Perfectly Matched Layer (PML) are in common use. Nevertheless, only a few incomplete comparisons of these boundary conditions were published.

In this paper, the first part will summarize the theoretical background of both the general HABC based on the Renaut series expansion [1] and the PML technique based on the formalism of Berenger [2]. I introduce an improved HABC with regard to efficient use of computer ressources. Next, I propose the Huygens-source to calculate the reflection coefficient of a plane wave travelling toward the boundary at an arbitrary angle of incidence. Against the background of wave propagation in optoelectronic devices I present a comprehensive and comparative study of the HABC and the PML techniques. For a useful comparison I consider the reflection coeÏficient as a function of the angle of incidence and the reflectivity spectra to demonstrate the performance of the boundary conditions for dispersive applications.

Finally, I classify the boundary conditions with respect to practical applications and evaluate the results against the background of current research.

References

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[2] J.P. Berenger, 'A perfectly matched layer for the absorption of electromagnetic waves', Journal of Computational Physics, vol. 114, pp. 185-200, 1994

Equivalence of Linear and Exponent Time-Stepping Forms in PML Medium

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With amazing increase of computer speed and memory in the last decade, the numerical computations of applied electromagnetics have been developed fast. Among all computational methods, finite-difference time-domain (FDTD) method is special attractive to people. In order to decrease computation domain in the FDTD method, various absorbing boundary conditions (ABC's) are extensively investigated. One of the best ABC's is perfectly matched layer (PML) method. In the perfectly matched layer medium of the PML method, differential formulas are written in exponential time-stepping forms [1] which are derived from a wave special solution in loss medium [2]. Such exponential forms are a little bit of inconvenience in comparison with the linear time-stepping forms [3]. However, the numerical experience indicates that using linear time-stepping forms instead of the exponential time-stepping forms in the PML medium is permitted [4]. We will prove the above two time-stepping forms are equivalent by means of mathematical derivation.

References

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Tuesday, July 14, PM 13:40-18:20
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Organiser : Yu. V. Shestopalov

Chairs : Yu. V. Shestopalov, Kazuya Kobayashi

An Analysis of Modal Coupling and Cutoff Properties of Open and Closed-Boundary Waveguides Using Singularity Theory

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An analysis of the coupling and cutoff properties of modes of open and closed-boundary waveguides is presented based on the mathematical tools of singularity theory. It is assumed that modal properties are obtained from the zeros of some operator-valued function or explicit transcendental equation H(k,w)=0, where k and w typically represent propagation constant and frequency, respectively. Classical mode coupling of codirectional waves and contradirectional waves is explained from the theory of Morse critical points, which have been applied by previous investigators for such problems. Necessary and sufficient conditions are stated for modal degeneracy of uncoupled modes, leading to the normal form (codimension 1) associated with H of two intersecting straight lines. Typical mode coupling is predicted by the universal unfolding of H, resulting in coupling of codirectional waves or contradirectional waves.

Modal cutoff properties of traditional propagating modes and complex modes in closed-boundary waveguides as well as leaky modes in open-boundary waveguides are predicted from the concept of fold or limit points in singularity theory. The normal form for such points (codimension 0) is its own universal unfolding, such that the characteristic intersection of a parabola and a straight line observed in the modal cutoff region is persistent. This implies that the critical point type remains the same for small perturbations, although the location of the critical point may move about, typically into the complex plane for small perturbations such as the addition of material loss. It is shown that such limit points are square-root type branch points, and necessary and sufficient conditions for the occurrence of such branch points will be stated. Additional observations concerning the occurrence of non-analytic modal behavior occurring at the coalescing of individual waveguide modes will be provided.

Plane Wave Diffraction by a Strip with Different Surface Impedances

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Analysis of the scattering and diffraction by imperfectly conducting and absorbing strips is an important subject in electromagnetic theory, and it is relevant to many engineering applications such as antenna and radar cross section (RCS) studies. This structure serves as a suitable model of finite metal-backed dielectric layers and dielectric-coated wires. The diffraction by strips with the standard impedance boundary condition (SIBC) has been investigated using high-frequency and numerical methods (T. B. A. Senior, *IEEE Trans. Antennas Propagat.*, vol. AP-27, pp. 808-813, 1979; R. Tiberio, F. Bessi, G. Manara, and G. Pelosi, *Radio Sci.*, vol. 17, pp. 1199-1210, 1982; M. I. Herman and J. L. Volakis, *Radio Sci.*, vol. 22, pp. 335-349, 1987). In the previous papers (E. I. Veliev, K. Kobayashi, T. Ikiz, and S. Koshikawa, *Proc. 1996 International Symposium on Antennas and Propagation*, pp. 17-20; E. I. Veliev, K. Kobayashi, T. Ikiz, and S. Koshikawa, *Proc. 6-th International Conference on Mathematical Methods in Electromagnetic Theory*, pp. 354-357), we have analyzed the plane wave diffraction by an impedance strip using the analytical-numerical approach based on the orthogonal polynomial expansion (E. I. Veliev and V. V. Veremey, *Analytical and Numerical Methods in Electromagnetic Wave Theory*, Chap. 10, M. Hashimoto, M. Idemen, and O. A. Tretyakov, eds., Science House, Tokyo, 1993), where the efficient solution has been obtained for the same surface impedances on both sides of the strip. It is to be noted that our analytical-numerical approach is entirely different from the methods employed previously for analyzing impedance-related problems. In this paper, we shall consider a strip with different impedances on its two surfaces as an important generalization to our previous analysis, and solve the plane wave diffraction rigorously. The method of solution is again based on the analytical-numerical approach.

We consider the strip illuminated by an E-polarized plane wave, where the strip occupies the region $|x| < a$ of the $y = 0$ plane. The strip is assumed to be infinitely thin and uniform in the z -direction. The E polarization implies that the incident electric field is parallel to the z -axis. On the strip surface, the total tangential field components satisfy the SIBC, where the surface impedances on $y = +0$ and $y = -0$ are different from each other in sign. Applying the boundary condition to an integral representation of the scattered field, the problem is formulated as two integral equations satisfied by the unknown current density function. Expanding the current density function in terms of the Chebyshev polynomials, our problem is reduced to the solution of two infinite systems of linear algebraic equations (SLAE) satisfied by the unknown expansion coefficients. These coefficients are determined numerically with high accuracy via a truncation of the SLAE. Evaluating the scattered field asymptotically, a far field expression is derived. Numerical examples on the RCS are presented for various physical parameters and the far field scattering characteristics are discussed in detail. Some comparisons with the results in the paper by Tiberio et al. mentioned above are also given to validate the present method.

Pseudodifferential Equations Method forElectromagnetic Screen Problem in R^3

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We study the electromagnetic scattering problem on a bounded screen. The surface of the screen is assumed to be infinitely thin and perfectly conducting. Let Ω be the two-dimensional bounded surface in R^3 with the smooth boundary $\partial\Omega$ outside a finite set of singular points. The problem can be reduced to the vector pseudodifferential equation on manifold Ω

$$Lu := Grad\Delta^{-1/2}(Divu) + k^2\Delta^{-1/2}u = f, \tag{1}$$

where Δ is the Laplacian, $f := 4\pi k E_t^0\big|_\Omega$ $(k \neq 0)$, Div and $Grad$ are the tangential operations on Ω. Here, the tangential vector u is the so-called current density on Ω.

Note that the principal symbol of equation (1) is degenerated. In order to study equation (1), the Sobolev space W is introduced in accordance with the asymptotic behaviour of solution u near the edge $\partial\Omega$. Define the space of distributions W as the closure of $C_0^\infty(\Omega)$ in the norm

$$\|u\|_W^2 = \|u\|_{-1/2}^2 + \|Divu\|_{-1/2}^2.$$

One can show that

$$W = \{u \in \tilde{H}^{-1/2}(\overline{\Omega}); Divu \in \tilde{H}^{-1/2}(\overline{\Omega})\},$$

where $\tilde{H}^s(\overline{\Omega})$ denotes the Sobolev space. Using the method of quadratic forms one can show that it is possible to consider L as a bounded operator $L: W \to W'$. Here, W' denotes antidual space for W: $W' = \{u|_\Omega : u \in H^{-1/2}(M), Rot u \in H^{-1/2}(M)\}$, where M is the closed surface such that $\overline{\Omega} \in M$.

Theorem 1 *For* $\operatorname{Im} k \geq 0$ *and* $k \neq 0$ *there exists exactly one solution of the equation*

$$L(k)u = f, \quad u \in W,\ f \in W' \tag{2}$$

We prove the limiting absorption principle. Let $\operatorname{Im} k \geq 0$ and $k \neq 0$. Then the bounded operator-function $L^{-1}(k): W' \to W$ exists and depends analytically on k in the neighbourhood of every real point $k_0 \neq 0$. This implies

Theorem 2 *Let* $\operatorname{Im} k \geq 0$, $\operatorname{Im} k_0 > 0$, $k_0 \neq 0$ *and* $f(k) \xrightarrow{W'} f(k_0)$ *weakly as* $k \to k_0$. *Then* $u(k) \xrightarrow{W} u(k_0)$ *strongly as* $k \to k_0$, *where* $u(k)$ *and* $u(k_0)$ *solve the problems* $L(k)u(k) = f(k)$ *and* $L(k_0)u(k_0) = f(k_0)$.

Consider a singular point $P \in \partial\Omega$, where $\partial\Omega$ consists of two arcs of two smooth curves intersecting transversally at the singular point. If $\alpha(P)$ is the interior angle of the tangent cone to Ω at $P \in \partial\Omega$, then $\alpha(P) = \pi$ if P is a regular point and $0 < \alpha(P) < 2\pi$, $\alpha(P) \neq \pi$ for singular points. Let $f \in C^\infty(\overline{\Omega})$. We apply the regularity theory for equation (2) to determine the values β of the critical exponent for singularities of the solution $|u| \leq Cr^{-\beta}$ near the corner point P, where r is the distance to the point P:

α/π	0.	0.0500	0.1250	0.2500	0.3750	0.5000	0.6250	0.7500	0.8750
$\tau(\alpha)$	1.0000	0.8705	0.8317	0.7820	0.7384	0.6956	0.6517	0.6057	0.5561

α/π	1.0000	1.1250	1.2500	1.3750	1.5000	1.6250	1.7500	1.8750	2.0000
$\tau(\alpha)$	0.5022	0.4448	0.3799	0.3073	0.2277	0.1444	0.0702	0.0281	0.

Explicit Expressions for the Spectrum of Normal Waves of an Open Slot Waveguide

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The problem of normal waves of an open slot waveguide is considered. In the cross section, the boundary surface of this waveguide-a partially shielded dielectric pivot is formed by an unclosed circular arc, and the permittivity is a piece-wise constant function of transverse coordinates.

The initial electromagnetic problem is reduced to the equivalent system of integrodifferential equations, whose kernels analytically depend on the spectral parameter γ (the propagation factor). Thus, the problem consists in evaluating the singular points of operator $K(\gamma)$ of the system, that is, the points, at which operator $K(\gamma)$ loses its invertibility.

The size of the slot of the waveguide is chosen as a small parameter of the system. This circumstance enables one to invert the operator of the problem with the accuracy sufficient for the analysis of its singular points. The latter are just the poles of the inverse operator $K^{-1}(\gamma)$ and are expressed in the form of expansions in powers of l and logarithms of l.

The principal waves of the cylindrical slot line of a circular cross section are established, as well as other types of normal waves. Classification of the normal waves is given, and both the real and imaginary parts of the propagation constants are evaluated.

The method is applicable to waveguides with several slots and can be extended to open slot waveguides formed, in the cross section, by unclosed contours that differ from circular arcs.

Reconstruction of a Singular Potential in the Multidimensional Schroedinger Equation with Applications to the Wave Scattering

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The multidimensional Schroedinger equation with a singular arises in mathematical models of quantum mechanics, acoustics, and the wave propagation in layered dielectric waveguides. The necessity of studying the Schroedinger operator with a singular potential follows from some well-known problems of mathematical physics and, in particular, it is very important also to study the points of singularity of this potential. We consider some inverse problems of reconstructing this singular potential and singular points of this potential and propose some new methods and ideas. The inverse scattering problem for the Schroedinger operator is to reconstruct the potential from the scattering data. In our case, the scattering data is the scattering amplitude, which corresponds to the far field measurements of a set of scattering solutions of the Schroedinger equation.

New estimates for the resolving of the Hamiltonian on the continuous spectrum plays the crucial role in our considerations. Using these estimates, we prove the well-known Saito's and Newton's formulas for the unknown singular potential. In addition to this, we can consider the Born-approximation of our potential. An obvious advantage of this approximation is the possibility of replacing the original nonlinear inverse problem by a simple linear one: within the born-approximation, the scattering amplitude is simply the Fourier transform of the unknown potential. It is shown that the Born-approximation exactly reproduces the discontinuity-type singularities and the leading order infinite-type singularities of the true potential. We also prove the new asymptotical formula for the Fourier transform of the unknown potential. This formula contains only the Green's function of the Hamiltonian.

Method Based on Singular Integral Equations for Solving Nonhomogeneous Diffraction Problem

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A system of singular integral equations is used to model the problem of diffraction by a finite nonhomogeneous body, whose permittivity $\hat{\varepsilon}(x)$ and permeability $\hat{\mu}(x)$ are arbitrary tensor functions. In 2D case, when $\hat{\mu}(x) \equiv \mu_0 \hat{I}$ and magnetic vector is parallel with z axis ($\mathbf{E} = \{E_1, E_2, 0\}$ in Cartesian system), the system becomes the following vector equation :

$$\mathbf{E}(x) + \frac{1}{2}\left(\frac{\hat{\varepsilon}(x)}{\varepsilon_0} - \hat{I}\right)\mathbf{E}(x) - k_0^2 \int_Q \left(\frac{\hat{\varepsilon}(y)}{\varepsilon_0} - \hat{I}\right) G(r)\mathbf{E}(y)dy$$

$$-V.p.\left\langle \int_Q \left(\frac{\hat{\varepsilon}(y)}{\varepsilon_0} - \hat{I}\right)\mathbf{E}(y), grad_x \right\rangle grad_x G(r)dy = \mathbf{E}^{(0)}(x), x \in Q$$

where $G(r) = \frac{i}{4} H_0^{(1)}(k_0 r)$, $E^0(x)$ is an incident field, $\langle .,. \rangle$ denotes scalar product. In general situation, when both $\hat{\varepsilon}(x)$ and $\hat{\mu}(x)$ are variable over the finite domain Q, the system contains two coupled vector equations in electric and magnetic fields as unknown quantities. The system can be derived from Maxwell's equations using vector potential formulas. Investigation of sungular system is performed in two different ways, depending on media properties. In the first case, components of electric and magnetic tensors are assumed to be continuos over the whole space, and the theory of multidimensional singular integral equations is used to find conditions under which the system is Fredholm. It is proved, that if the following inequalities hold : $\inf_{x,n} |\langle \hat{\varepsilon}(x)\mathbf{n}, \mathbf{n}\rangle| > 0$, $\inf_{x,n} |\langle \hat{\mu}(x)\, \mathbf{n}, \mathbf{n}\rangle| > 0$, where $\mathbf{n}$ denotes arbitrary unit vectors, and a number of additional conditions are satisfied (presence of at least infinitely small losses in the object), then the solution exists and is unique in $L_2(Q)$. If the tensor components are artitraty functions over Q and $\hat{\varepsilon}(x) \equiv \varepsilon_0 \hat{I}$, $\hat{\mu}(x) \equiv \mu_0 \hat{I}$ as $x \notin \overline{Q}$, applying an iterative method to the singular operator in functional space proves an existence and unique ness theorem. In both cases, conditions for the existence of classical solution and an equivalence of differential and singular integral formulations are investigated.

To solve the problem numerically, the singular equations are discretized using collocation or the Galerkin method. Then, a Multistep Minimum Discrepancies Method is used to solve the resulting algebraic system. A number of calculations were performed in order to compare numerical results with known exact solutions.

Analytical Regularization Methods in Diffraction Theory

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The report is aimed to cover the present state of art of Analytical Regularization Methods, that have been employed in solving boundary value problems in mathematical physics and having found their application in diffraction theory. It is consistently implementing the idea of analytical regularization of ill-conditioned surface integral or integral-differential equations and single or double series equations of the first kind.

The methods reduce such equations to well-conditioned linear functional equation of the second kind and give the basis for efficient numerical algorithms. This regularization technique are successfully used in studies of two- and three-dimensional problems of wave scattering by closed and unclosed screens, compact and periodic, dielectric and impedance or perfectly conducting scatterers.

The central point of Analytical Regularization Methods is the problem of constructing in closed analytical form the regularizator of the original boundary value problem operator $\boldsymbol{A}$. The regularizator is a pair $(\boldsymbol{L}, \boldsymbol{R})$ of two operators $\boldsymbol{L}$ and $\boldsymbol{R}$, that $\boldsymbol{LAR}=\boldsymbol{I}+\boldsymbol{H}$, where $\boldsymbol{I}$ and $\boldsymbol{H}$ are correspondingly identical and compact operators in relevant the Hilbert space. By means of this regularizator, the original boundary value problem can be reduced to the equation of the second kind: $(\boldsymbol{I}+\boldsymbol{H})\boldsymbol{x}=\boldsymbol{b}$ in the Hilbert space of square sumable sequences with unknown infinite vector-column $\boldsymbol{x}$. The last equation can be numerically solved (by means of truncation method) with, in principle, arbitrary required accuracy. As it is well known, this solving process is numerically stable because of uniform boundness of truncated matrices condition numbers.

There exist a few analytical techniques for regularizator constructing. Among them, the method of the Riemann-Hilbert problem and methods based on the different integral transformations, such as Fourie transform, partial differentiation or integration and some others.

Nowadays, it was discovered, that the classic Orthogonal Polynomials Method can be considered as the basis for corresponding regularizator constructing too (see [1]).

Results of numerical modeling based on Analytical Regularization Methods for different classes of diffraction problems and scatterers will be discussed in the report.

Reference

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High-Q and Low-Q open Resonators : Methods, Results, and Perspectives

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In general, eigenfrequencies of open (2-D, or cylindrical, and 3-D) resonators (electromagnetic and acoustic) are complex eigenvalues (with the negative imaginary part) of nonselfadjoint boundary value problems for the Maxwell and Helmholtz equations in unbounded domains (in particular, with noncompact nonperiodic boundaries), where conditions at infinity differ from the Sommerfeld conditions and contain the spectral parameter (frequency ω). Eigenvalue problems are reduced to generalized dispersion equations (GDEs)

$$K(\omega, \mathbf{a})\varphi = 0,$$

where K is a multi-parameter (usually, Fredholm and analytical or finite-meromorphic) operator-valued function (OVF), which defines implicitly the eigenfrequencies $\omega = \omega(\mathbf{a})$ as generalized dispersion curves (GDCs) with respect to the vector of nonspectral parameters $\mathbf{a}$ [often, $K(\omega, a_0)\varphi \equiv \int_L K(\omega; t, s)\varphi(s)ds$ with $\mathbf{a} = a_0 = diam\, L$ is an integral OVF, or an infinite-matrix OVF $\| k_{mn}(\omega, \mathbf{a}) \|^{\infty}_{m,n=1}$].

Well-developed methods of spectral theory are insufficient to prove *existence* of complex eigenvalues for the majority of such structures. In this way, we develop the functional parameter-continuation technique and apply the above formalism of implicit OVFs to establish the existence directly and to calculate GDCs not only by numerical methods but also in the form of classical asymptotic series with the estimated remainder.

We prove that high-Q resonances are characteristic of a specific family of slotted image-type structures with narrow slots (and their Q-factor may be arbitrarily high), so that all complex eigenfrequencies may be arbitrarily close to the real axis, namely, to (real) eigenvalues of a bounded volume perturbed by the slot (the case of regular perturbation). Note that the corresponding rigorous proofs are not trivial as it might seem at first sight (e.g., for such a simple structure as an open resonator formed by three parallel infinite planar screens with a small hole in the central one, regular perturbation is not valid) and are not available in the literature.

Low-Q resonances are discovered (by the parameter-continuation method) for resonators that cannot be considered as (regular) perturbations of closed domains (e.g., perfectly conducting screens with cylindrical cavities and protuberances, cylinders of arbitrary cross sections covered with dielectric, etc.). Although the corresponding eigenfrequencies are situated far from the real axis in the complex plane ω, we show (by considering far and near field patterns and the magnitudes of other integral and power field characteristics with respect to the varying frequency of the incident field) that such low-Q open resonators demonstrate very distinct resonant features.

Projection Method to Investigate the Two Dimension Problem of the Wave Scattering by a Metallic Cylinder of Arbitrary Shape in the High Frequency Domain.

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It's well known that the classic Fourier method is not applicable to the diffraction problems for the obstacles of arbitrary shape. Projection methods of Galerkin type are the natural generalizations of Fourier method, especially their non-complete variants using the solutions Fourier expansions with respect to the particular eigen solutions of angular coordinate. According to such a scheme the unknown Fourier coefficients evaluation may be reduced to the boundary value problem for the infinite system of ordinary differential equations with variable matrix. The truncated system one can solve numerically to obtain the approximate solution. Nevertheless the slow convergence of the approximate solution to the exact one for the high frequency makes this approach useless in case of short waves diffraction problems. Sommerfeld solution of the diffraction problems for a sphere or circular cylinder using the singular eigen solutions of radial coordinate as the basis of an expansion gives the single example of rapidly converging in high frequency region series.

The generalized Sommerfeld approach for the obstacles of arbitrary shape (such as a circular cylinder with dielectric coating of variable thickness) assumes the corresponding projection method using the cylindrical functions of complex indexes as the basis of an expansion satisfying the prescribed boundary condition. If the metallic obstacle also has non coordinate boundary (what is the subject of the paper) such a generalization is as well possible if the cylindrical functions with variable complex indexes,- functions of angular coordinate, are used

$$\psi_{\nu_k(\varphi)}(r) = H^{(1)}_{\nu_k(\varphi)}(\mathrm{kr}), \quad \mathrm{k} = 1, \ldots \infty,$$

where ###$_k(\varphi)$ are the roots to the dispersion equation

$$H^{(1)}_{\nu_k(\varphi)}(\mathrm{k}\rho(\varphi)) = 0.$$

This system of functions is orthonormal over the variable half infinite interval of radial coordinate and is as well the basis of the Hilbert space with the mean square norm. The corresponding boundary value problem solution may be expanded in the Fourier series with respect to these basis functions

$$\hat{u}(r,\varphi) = \sum_k A_k(\varphi)\, \psi_{\nu_k(\varphi)}(r).$$

It reduces the initial problem to the ordinary differential equations system for the unknown functions $A_k(\varphi)$ of angular coordinate due to the conditions of decay in the infinity. The periodical angular solution is obtained as the infinite sum of the non periodic solution branches

$$\tilde{u}(r,\varphi) = \sum_{-\infty}^{\infty} \hat{u}(r, \varphi + 2\pi n).$$

It's proved that the good approximation to the solution may be achieved on solving only the system diagonal independent equations and using the WKB approach. Finally the evident asymptotic solution,- generalized Watson series rapidly converging in high frequency region is obtained. In the case of a smooth metallic obstacle the final formulae are similar to those in Keller diffraction theory.

The solution Fourier expansion using Sommerfeld type basis functions has more broad region of applications than the usual angular Fourier expansion. Particularly neither Raileigh hypothesis problems nor the case of the boundary with the angles are the obstacles for its application. It makes such a representation more adequate to the diffraction phenomena in the finite obstacles cases.

Surface and leaky guided waves on dielectric fibres of arbitrary cross-section

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The mathematical model describing surface and leaky guided waves on dielectric fibres of arbitrary cross-section is studied. The guided waves propogating along axis z of the fibre by the law $\exp[i(\beta z - \omega t)]$, where an axial propagation coefficient β is unknown complex parameter, ω is a given frequency of electromagnetic fluctuations, are sought.

On the assumption of closeness of real refractive indexes of fibre and environment this phisical problem is reduced to the spectral problem for the Helmholtz equation on plane with Reichardt conditions on infinity. Both surface exponentially decreasing waves and exponentially growing on infinity leaky waves satisfy these conditions.

This initial problem may be reduced to nonlinear spectral problem for Fredholm holomorphic (on some Rieman surface) operator - valued function by the equivalent way with the help of potentials of simple layer.

The questions of spectrum localization were studied. There was shown that propagation coefficient of the surface waves my belong only to some real axis interval determined by refractive indexes and frequency of electromagnetic fluctuations and that the propagation coefficient of leaky waves may belong to some vertical semi-stripe that adjoints to positive imaginary semi-axis. Consequently leaky waves exponentially decay along fibre axis. These results generalize the results of Katsenelenbaum considering spectrum localization of the surface and leaky guided waves on fibres of circulary cross-section, he received on the basis of the analysis of the characteristic equation of the method of separation of variables.

It was demonstrated that the spectrum of surface waves, so as of leaky ones may consist only of isolated points.

It was constructed a system by Galercin method based on use of trigonometrical basis for numerical solution of the problem. Determinant zeros of the matrix of this system are assumed as the approximation values of the propagation coefficient. The convergence of this method was studied. The practical effectiveness of this method was shown by comparison of solution of some problems of the theory of dielectric fibres with experimental data and witch results received by other methods.

Scattering by an Infinite Grating with a Groove Structure of a Finite Size

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We study mathematical models describing the scattering of a plane electromagnetic wave by an infinite perfectly conducting grating with a groove structure of a finite size for arbitrary incidence angles. We consider the gratings having arbitrary profiles with finite number of edges. As a special case of gratings periodic structures [1, 2] are treated.

As a mathematical model we use the boundary value problems for the two-dimensional Helmholtz equations with complex-valued wave number, the Dirichlet and Neumann boundary conditions (depending on the polarization of the incident wave), the edge condition of the first kind (condition of finite energy) at the edges of the boundary and the radiation conditions at infinity.

The existence and uniqueness of the problem are proved in the Hilbert space of square integrable functions. In case of a smooth boundary we proove classical solvability of this problem [3]. We show that this problem is reduced to a solving for a Fredholm integral equation of the second kind on a finite interval. Then we derive the equivalence between the integral equations and the scattering problem. We show that a solution of the problem is represented by a double layer potential (in the case of the plane E-polarized wave) and by a simple layer potential (in the case of H-polarized wave) whose density is a solution of a corresponding integral equations.

The computer algorithms for finding the electromagnetic fields scattered by these gratings are based on methods of numerical solutions of the integral equations with weakly singular kernel. A numerical solution of the integral equations is constructed by the method of averaging functional corrections (a version of the projection-iterative methods) [4] and by spline-quadrature method.

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On the Electromagnetic Scattering Problem for a Perfectly Conducting Infinite Cylinder Contained in the Wedge

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We consider a boundary value problem arising in the study of diffraction of time harmonic electromagnetic waves of E-polarization by a perfectly conducting infinite cylinder of arbitrary cross-section contained in the homogeneous wedge with the edge parallel to the axis of the cylinder.

Introduce in $\mathbf{R}^3$ the cylindrical coordinate system r, Φ, z and denote by $w = \{(r,\Phi,z) \in R^3 | r > 0, 0 < \varnothing < \Phi, -\infty < z < +\infty\}$ a wedge with perfectly conducting walls and the spread angle $\Phi, (0 < \Phi \leq 2\pi)$ and with the edge coinciding with the z-axis. Denote by C a perfectly conducting infinite cylinder with the axis parallel to the edge of the wedge. We will suggest that the domain $W \setminus \overline{C}$ is filled by homogeneous isotropic medium with electric and magnetic permittivities $\in$ and μ respectively and electric conductivity σ.

Let Ω and D be the domains obtained as a result of intersection of the wedge W and the cylinder C with the plane z = 0 respectively. We assume that $\overline{D} \subset \Omega$, and the domain $\Omega \backslash \overline{D}$ is connected and the boundary of the domain D is a Liapynov surface. Denote by $\partial\Omega$ the boundary of the angular domain Ω.

Let a linear source of a time harmonic cylindrical wave be a thread of electric current spaced in the domain $W \setminus \overline{C}$ in parallel with the edge of the wedge. Consider the problem of diffraction of the E-field excited by this source on the cylinder C. This problem is to determine the field with components which do not depend on z and which may be represented by means of one potential function u(r, $\varnothing$), satisfying the Helmholtz equation

$$\Delta u(r,\varnothing) + k^2 u(r,\varnothing) = 0, \ (r,\varnothing) \in \Omega \backslash \overline{D}\,; \tag{1}$$

boundary conditions

$$u = -E_z^{(i)} \text{ on } \partial D, \ u = 0 \text{ on } \partial\Omega\,; \tag{2}$$

the Sommerfeld radiation condition

$$\frac{\partial u(r,\phi)}{\partial r} - iku(r,\phi) = 0\left(\frac{1}{\sqrt{r}}\right), \ r \to \infty, \tag{3}$$

uniformly in ϕ and the condition on the edge of the wedge. Here $k = \sqrt{\omega^2 \in \mu + i\sigma\omega}, \operatorname{Im} k \geq 0, \omega$ is a frequency of change of the field (it considers that the wave process depends on time in the form $e^{-i\omega t}$), Δ is the Laplace operator in polar coordinates,

$$E_z^{(i)}(r,\phi) = \frac{i\pi}{\Phi} \sum_{m=1}^{\infty} \sin\left(vm\phi^*\right) \sin(vm\phi) J_{v_m}\left(k \min\left(r^*, r\right)\right) H_{v_m}\left(k \max\left(r^*, r\right)\right),$$

where $\left(r^*, \phi^*\right) \in \Omega \backslash \overline{D}$ is the point of intersection of the linear source with the plane z = 0, $J_v(x)$ are the Bessel and the Hankel functions respectively, $v_m = m\pi / \Phi$, m = 1,2,....

We have developed the potential theory enabling us to reduce the boundary value problem (1)-(3) to one-dimensional Fredholm integral equation on the boundary ∂D of the cross-section of the cylinder with the kernel having at most logarithmic singularity. We prove existence and uniqueness of solutions both for this integral equation and for the boundary value problem. We also represented the kernel of integral equation as rapidly convergent series.

Session E03
Tuesday, July 14, PM 13:40-17:00
Room K
Genetic Algorithm and Optimization

Organiser : H. J. Mametsa

Chairs : H. J. Mametsa, Y. Rahmat-Samii

Genetic Algorithms : Optimization Design Tools in Engineering Electromagnetics

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Since the early part of this decade, Evolutionary Optimization (EO) techniques have been applied with growing applications to the design of electromagnetic systems of increasing complexity. The recent popularity experienced by EO methods is not unique to the field of electromagnetics; in fact, EO techniques have been successfully applied to problems in fields ranging from engineering to economics and artificial intelligence. Among various EO's, Genetic Algorithms (GA) have attracted much attention. The foundation of GA is based on Darwin's evolutionary philosophy, i.e., "the survivability of the fittest species". GA schemes are finding popularity in electromagnetics as design tools and problem solvers because of their versatility and ability to optimize in complex multimodal search spaces applied to non-differentiable cost functions.

The aim of this presentation is to provide the electromagnetics community and modern antenna designers with an up to date body of knowledge on the application of GA techniques to the synthesis and optimization of electromagnetic systems. Specifically, this talk will focus on: (a) engineering introduction to Genetic Algorithms by reviewing simple GAs and their standard terminology and operators (populations, parents, children, chromosome, selection, crossover, and mutation), (b) by demonstrating the potential application of GAs to a variety of electromagnetic engineering designs including microstrip antennas, multi-band and wideband antennas, synthesis of non-planar radar absorbing materials for RCS applications, etc, and (c) by assessing the advantages and the limitations of the technique.

One the Use of the Genetic Algorithm for RCS Modelling

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The computation time needed to calculate RCS from a complex structure (like ships, aircraft and tanks) mays be too long when one wants to apply such models in operational radar analysis. In order to decrease this computation time, one may use a generic model defined by many scatterers like bright spots and canonic structures (plates, cylinders, dihedrals, trihedrals, sphere, and so on...) which are supposed uncoupled so that their contribution to the RCS are the sommation in amplitude and phase of the field diffused by each of the scatterers for a given direction and polarization. The main difficulty to estimate the parameters for each of the scatterers (center position, dimension and scattering direction) is that this is a non linear problem, so that classical algorithms which use conjugate gradient and partial derivations do not really work. A good way to estimate these parameters is the use of the genetic algorithm because it does not need the computation of derivation for the parameters, is well-adapted for non linear estimation problems and ensures that each of the parameters to be optimized will stay into a user defined bound domain. Defining a cost function which indicates the accuracy between the computed RCS by the generic model and the computed or measured RCS of the structure, the genetic algorithm creates generation after generation a new set of genes from the old one and only keeps the best ones so that the cost function decreases. The optimized parameters will be those of the gene whom the cost function will be the smallest. Instead of using a discrete representation of the parameter in the gene, we prefer to use a continuous one which seems to be more adapted for this kind of problem and gives better results.

Numerical Solution to the Electromagnetic Scattering by Nonlinear Object by Using Genetic Algorithms

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This paper deals with the application of an optimization procedure based on a genetic algorithm to the prediction of the electromagnetic fields scattered by weakly nonlinear dielectric objects. Starting by an integral approach [1] and describing the nonlinearities of the constitutive parameters by the Volterra-type integrals, the nonlinear scattering problem is numerically solved by an iterative procedure developed for the minimization of a suitable defined cost function (the so-called *fitness function*). A genetic algorithm [2] is applied in order to deal with a large number of unknowns related to the harmonic components of the nonlinear internal electromagnetic field. The genetic algorithm starts by choosing M trial field solutions, which constitutes the initial *population* (usually we indicate as *population* the set of trial solutions that are used, at each iteration, to span the solution space). Each trial solution (or *individual*) is coded in a binary sequence called *chromosome*. Then, the algorithm generates a new population of trial arrays by using three mechanisms: *selection*, *crossover* and *mutation*.

Once the new population has been generated, the fitness function of each individual is evaluated and the genetic algorithm restarts with a new generation or terminates if the solution has been achieved (i.e., a fixed numerical threshold for the stopping criterion is reached) or when the iteration loops are terminated.

Numerical examples illustrate the features of the genetic algorithm as applied to the nonlinear scattering. In particular, we focus the attention on the convergence question and among the numerical results provided by other methods, are performed and discussed in more detail.

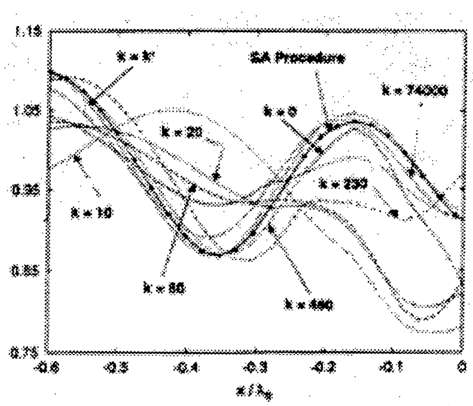

Figure 1 : Amplitude of the first harmonic term of the total electric field computed along the propagation axis of a nonlinear circular cylinder (Kerr-type nonlinearity) illuminated by an incident TM plane wave (*k*: iteration number).

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A Wire Antenna Designed for Use on the Lossy-Earth Interface Using a Genetic Algorithm

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A wire antenna is designed for optimal performance at low elevation angles in the presence of a lossy half-space. A simple genetic algorithm (GA) and GENOCOP III software are each integrated with Numerical Electromagnetics Code Version 4.1 (NEC4.1) to optimize a wire antenna geometry for the multiple objectives of power gain, azimuthal symmetry, and input impedance, using a novel approach for implementing a weighted sum of the objectives. The performance of the two versions of the integrated GA are compared, and the simple GA is clearly outperformed by the GENOCOP III version in terms of both finding peak fitness values and the resulting antenna performance. Three different geometry paradigms are investigated, and some of the resulting antennas are analyzed. The vertical loaded monopole (VLM) geometry is shown to be the best geometry given the problem constraints, and the corresponding optimized antenna is proposed for use in a Remote Intrusion Monitoring System (RIMS). Simulations using NEC4.1 suggest that the VLM antenna is closely matched to a 50 Ohm (Ω) feed line and offers a significant increase in power gain at low elevation angles compared to a quarter-wavelength monopole. In addition, the performance of the proposed antenna surpasses that of the monopole at the extreme and middle frequencies of the 138-153 MHz band. The VLM is also studied over flat-earth models with electrical characteristics corresponding to the extremes of dielectric and quasi-conducting media, and the VLM performance is shown to be sufficient in the presence of these different conditions. Finally, the effect of random, Gaussian-distributed errors in the geometry of the wires is investigated for three different values of variance, and the VLM performance shown to be only slightly affected by such geometry errors.

Pattern Synthesis of Antenna Array by an Improved Genetic Algorithm Using Non-Uniform Probability Density Function

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In the design of an antenna array, the number of variables of optimization equations becomes very large as the array size increases. Classical methods usually get trapped in local maximum and do not yield the best solution. In this study, we apply an improved Genetic Algorithm (GA) for pattern synthesis of several unequally spaced antenna arrays.

The advantages of using GA in pattern synthesis had been recognized in the past few years. Since GA is one of the optimization methods that are able to escape from local maximum. Besides, it is possible for GA to search a small portion of a large solution space and yield a nearly global optimum solution within reasonable time. Even so, there are still no promises that GA always give us the global solution since it works in a random nature.

Conceptually, GA works on a population of chromosomes and sequentially executes three main operations, named crossover, mutation and selection, in a random nature. Based on the survival of the more fit, GA will converge to better population iteratively. Practically, there are various ways to implement these three operations, and various modified versions are proposed continuously every year.

In the past, uniform probability distribution was usually (if not always) used for generating the masks needed for crossover and for bit mutation. This paper proposes an improved GA that uses some non-uniform probability distributions in executing the crossover and mutation operations. Different pdfs may be used in different generations to accelerate and ensure the convergence of GA such that better precision is usually achieved. This improved GA is then applied to synthesize several antenna arrays to demonstrate its capability, which include linear and planar arrays that are equally and unequally spaced.

A New Priority Rotation Methodology to Improve the Performance of Genetic Algorithms

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Genetic Algorithms (GA), have been used to provide solutions to different optimisation problems with various degrees of success. The major factor affecting their performance is the identification of the "eligible parents" for carrying the genetic information from one generation the next, as it has a direct bearing on the convergence pattern of GA. The simple "survival of the fittest" theory is not always found to lead to a fast enough convergence to a global optimum.

We suggest a novel method of priority rotation amongst the "eligible parents". We suggest the entire sequence of iterations be divided into a number of "epochs", each epoch made up of a number of (typically around 5) generations. While in the first epoch, individuals are graded on their fitness and their priorities (for reproduction) assigned accordingly, in the second epoch, the best individual is bypassed and the next (second) individual in the list gets the highest priority. This rotation continues in a circular fashion so that after a few epochs the priority of the best individual again becomes the highest. However to prevent highly unfit individuals making way to the mating pool, thus belying the basic principle of GA, only individuals with their fitness value at least half that of the best individual of the generation are considered for priority allotment.

This method has been found to be very effective especially for uni-modal problems, as it drives the solution past the local peaks towards a global optimum at a faster rate. Theoretically, this method is a logical extension of the Simple Genetic Algorithm (SGA) methodology, where the less fit individuals do not perish straight away, but only reproduce less frequently, ensuring that their genetic information is not totally lost, In our method, we are further ensuring that this information is actively used.

We have used the method comparatively with those suggested in [1] and [2] for solving Maximum Flow Problem and TSP respectively, with up to about 15-20% improvement in terms of the number of generations required for an optimal solution. The major advantage, however, is that the new method involves only minimal changes in the SGA methodology and further it is problem independent. Hence the time for execution of each generation is much less and the data structures required are simple when compared with problem specific methods.

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Design of Optical Devices Using Genetic Algorithms

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There are two traditionally major classes of algorithms in optimization, which are classified in calculus-based and enumerative techniques. Calculus-based methods have satisfactory performance when the use of gradient is appropriate to optimize a function. Enumerative techniques have better performance whenever the problem is of major complexity, for these techniques consist of searching values at the objective function at every point in the searching space, one at a time. Calculus-based techniques do not have a satisfactory performance when the objective function is of major complexity, that is, presenting high discontinuity, multiextremal surface, and so forth. Enumerative techniques not only present high computational consumption, but also break down on complex problems of moderate size; this situation is known as the *"curse of dimensionality"*.

New procedures of optimization, such as genetic algorithms, are being used among the two techniques described early. Genetic algorithms are searching algorithms which are based on the mechanics of selection and natural genetics. First, a population which is randomically generated must be evolved by the algorithm, so that a function be maximized. In the course of each generation, three basic operations are carried out: reproduction, crossover and mutation. At the end of such process, an evolved population in which the fittest individual (the one who represents the optimal point at the fitness function) is found, and is selected to extract its parameters concerning the objective function. GAs differ from most optimization methods in four ways: GAs work with a coding of parameters, and not with the parameters themselves; GAs search from a population of points rather than from a single point; GAs do not use derivatives and; they use probabilistic transition rules, and not deterministic ones.

In the last five years, due to their peculiar characteristics, GAs have been applied to a greater number of problems related to electromagnetic optimization. This has been a matter of great concern, for these objective functions in the electromagnetic realm are highly nonlinear, multiextremal, and nondiferentiable. Among some problems in which genetic algorithms have been applied are antenna designs, microwave and optical devices using dielectric multilayers.

This work focuses mainly on synthesis of optical devices, based on multilayer structures composed of dielectrics. During the optimization procedure there are two types of research involved, and which are represented by the thickness and refractive index of each layer. In synthesis of multilayer systems, the genetic algorithm must generate a starting design which will be optimizated during the processing - population evolved - resulting in the final optimizated design, obeying to constraints imposed initially.

Synthesis design of antireflection materials and rejection filters will serve as example, and the materials and filters' reflectivity will be plotted for the used designs, in order to make a better interpretation of the results through a band of wavelength be possible.

At last, the results obtained will be discussed, and they will be compared to those of previous publications, this will contribute to establish a critical analysis about the performance of genetic algorithms in this class of problems.

Design of Ultra-Wideband EMC Antennas Using the Genetic Algorithm

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In a recent publication [1], the application of the genetic algorithm (GA) for the design of ultra-wideband wire antennas for communication applications has been discussed. The broadband characteristics of the antenna have been obtained by inserting frequency-dependent loads, e.g., lumped RLC resonant circuits, along the wires. By optimizing the values of the RLC components, their locations on the wires, and the parameters of the matching network of the antenna, one can control the current distribution over the entire frequency band and thereby improve the broadband performance of the antenna. A variety of ultra-wideband antenna configurations, including the loaded monopole [1], twin whip and the kite antenna [2], have been designed by using the GA.

The objective of this paper is to present a broadband design for a loaded biconical wire antenna, covering the frequency range of 30 to 300 MHz. The biconical antenna is often used for Electromagnetic Compatibility (EMC) measurements of spurious EM radiation from electrical equipments. The use of the loads helps achieve certain desirable design features of the antenna, viz., low VSWR at the entire frequency band; radiation pattern that is close to omni-directional in the azimuth plane; maximum radiation at or very near the horizon for the entire frequency band; and, smooth system gain variation with frequency.

A loaded, eight-arm biconical antenna, that employs five loads in each of the arms, has been designed. The design procedure utilizes the Genetic Algorithm in conjunction with the method of moments, and simultaneously optimizes 23 parameters for the loads and the matching network. Numerical results show that the use of this GA-derived combination of antenna loads and the matching network can help realize a remarkably flat gain *vs.* frequency response for the antenna. To evaluate the performance of the antenna thus synthesized, we have compared it with that of the unloaded antenna. We have found that the gain of the loaded antenna is relatively superior in the lower frequencie range, because its impedance match is better. We have also found that although, on average, the gain level of the unloaded antenna is higher, it exhibits a suckout (dip in gain) at 200 MHz, which has to be eradicated by loading the antenna. In addition, loading improves the VSWR of the antenna over the entire frequency range. For instance, at 30 MHz, the VSWRs for the loaded and unloaded antennas are found to be 3.5 and 19.7, respectively, the latter being clearly unacceptable for most applications.

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Genetic Algorithm Optimization for RCS Scatterer Model

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In this paper, application of a novel procedure of optimization for an electromagnetic problem is presented. Genetic algorithm are used to optimize scattering pattems of target scatterer models. Multiscatterer models are under investigations at the CELAR/GEOS** center, at Bruz, France.

In radar scattering analysis, a target can be represented by a finite number of discrete point scatterers. This is often described as the multiscatterer target model. This model consists of a spatial distribution of point scatterers, each of which produces a scattered wave of specified amplitude and phase. The scatterers are extracted from Inverse Synthetic Aperture Radar (ISAR) processing.

ISAR images are performed by a 2D-FFT on measurement data. Range processing is calculated by an inverse FFT on a selected bandwidth and cross-range processing is performed from azimuth samples data. Appropriated ponderations remove the sidelobe effects and dominant scatterers are selected from a suitable threshold. In this study, measurements, images processing and extraction of the dominant scatterers are performed from CELAR facilities.

Validity of the generated scatterer lists leads to perform a comparison between the computed complex sum of scatterers and the average RCS of the measurements on the largest aspect angle.
The well-known constraint is the aspect angle dependance (non persistence) of scatterer model. In most cases, the "raw" scatterer lists do not provide a minimal error in ternis of scattering pattems. In order to minimize this error, determination of correct amplitude-phase for each scatterer becomes an important optimization step of the analysis.

A wide variety of optimization techniques are available but the traditional methods such as the "gradient methods" rapidly become inefficient. They are vulnerable to local minima and exhaustive checking of possible amplitude-phase assignment is a very tedious time consuming drawback.

A new global approach known as the Genetic Algorithms (GA) overcomes this problem.
GA provide robust search, they are computationnally simple. The main operators, selection, crossover and mutation will be presented and discussed. The principal features of GA lie in that 1) they operate from a population of points not a single point, 2) they operate with a coding of the parameter set, not the parameters themselves, 3) they do not use derivative or knowledge of the "cost function", 4) these algorithms are easy to program and quickly converge to the global solution.

Very good results are obtained conceming the optimization of RCS scatterer model. GA should be considered as a powerful optimization technique for electromagnetic problems.

Acknowledgments: this work was supported by CELAR/GEOS 31170 Bruz France

* ONERA-CERT/DEMR: Office National d'Etudes et de Recherches Aérospatiales Centre d'Etudes et de Recherches de Toulouse / Département Electromagnétique et Radar
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Session F03
Tuesday, July 14, PM 13:40-16:40
Room B/C
Aperture Antennas

Chairs : C. Chekroun, S. Toutain

Phase Error in Dual-Ridged Horn Antennas

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The calculation of phase slippage in the flare section of a horn antenna loaded with ridges is presented. The calculation is based on geometric tracing of the path lengths of the propagating electromagnetic field. The flare angles for the horn are assumed constant in the E- and H-planes and generate a quadratic phase error at the aperture. In either plane, the lines of equi-phase are cylindrical and appear to be emana-ting from the horn apex. A non-uniform phase distribution occurs because the path length between the apex and aperture is greater away from the aperture center, hence the propagating electromagnetic field travels different distances before arriving at the aper-ture. Loading the horn flare with ridges results in an additional increase in path length within the area occupied between the ridges at the aperture. If the ridge taper is not lin-ear, then the equi-phase lines between them are not cylindrical and the phase distribu-tion is no longer quadratic but related to the taper function. Knowledge of the phase con-tour is required to compute the field amplitude distribution as well, due to the oblique projec-tion factor of the vector fields across the horn aperture.

A New Type Miniaturized X-Ku Band Conical Horn and Helix Combination Antenna

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Small antennas with circular polarization are frequently used in alarge variety of applications. The typical choices are very limited when size, bandwidth, efficiency and simplicity are quite important. This paper proposes a new type of X-Ku band conical horn and helix combination antenna that seems to cope with all these requirements.

One of the well-known circular polarized small antenna is the conical or pyramidal horn when it is fed through the waveguide with equal-amplitude vartically and horizontally polarized modes arranged to be in quadrature. The pattern and VSWR bandwidth may be greater than a octave or more. But, however horn have the difficulty of attaining compact size and interconnecting microstrip feeding configurations. Axial-mode helix is the another well-known circularly polarized antenna, optimum axial- mode performance occurs when the pitch angle is about 14 degrees, the circumference is between $3\lambda/4$ and $4\lambda/3$, the gain is a function of the number of turns, and is about 10dB for a 6-turn helix. But instead the helix has the dificulty of attainning wideband, themaximum operational pattern bandwidth is les than 1.7:1.

The antenna proposed consists of a conical horn that is fed by a small helix with dielectric core for the 8-18 GHz (X-Ku) band. The antenna can radiate or receive right-hand ot left-hand circular polarization depending on the manner in which the helix is wound. The mutual coupling of the conical horn and helix is used to broaden the brandwidth considerably by appropriately choosing the conical horn and helix dimensions. Here the higher frequency band depends on the conical horn aperture size, and the lower frequency band depends on the circumference of the helix. The electromagnrtic properties of the test conical horn and helix combination antennas were investigated experimently. Antennas were fabricated with different conical horn sizes and with different turn helixes, thr total number of turns of helix, including the taper first turn, was varied over, five, four, three and two turns. Some interesting results are obtained. Experimental results are given, and prospective applications are discussed.

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Offset Characteristics of Elliptic Fresnel-Zone-Plate Lens

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1. Introduction

Fresnel-zone-plate lens (FZPL) can be used for satellite TV receptions, wireless LANs and radio telescopes. The paper treats the FZPL with a conical horn as receiving antenna by using Kirchhoff's diffraction integral formula and evaluates distributions of power flux density over the horn and receiving powers of the FZPL with horn.

2. Calculations and Measurements

Fig.1 shows an analytical model for the calculations in which the plane of z = 0 is FZPL shown in Fig.2 as an example and the point P(x2,y2,z2) is an observation point over the conical horn. Primary wave of the FZPL is an linearly polarized plane wave with an offset incident angle. The axis of the horn is on the line which passes through the axis of the FZPL and is parallel to the offset incident angle. Dielectric substrates which constitute some transparent parts of the FZPL are neglected in the calculations and are removed to a minimum quantity for maintaining its configuration shown in Fig.2 in the measurements. Fig.3 shows the offset characteristics of receiving power in the calculations and the measurements.

3. Conclusion

Both the calculations and the measurements show that maximum receiving power of the elliptic FZPL without dielectric substrates keeps constant along the offset incident angles, for which the projected area of the elliptic FZPL remains constant.

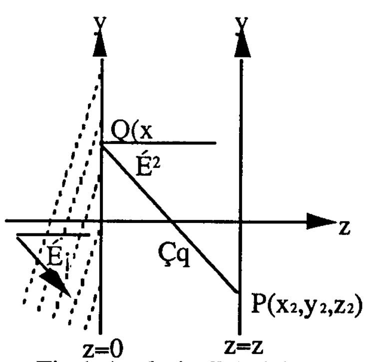

Fig.1 AnalyticalModel

Fig.2 Elliptic FZPL

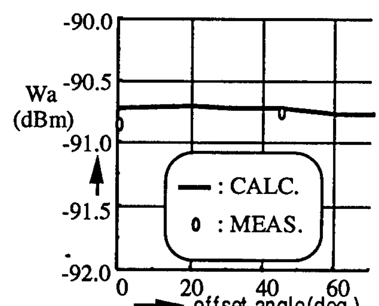

Fig.3 offset Characteristics

Phase Space Analysis and Aperture Theory : an Alternative to Gabor Series

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Accurate modeling of multireflector antennas, including surrounding structures (struts...), leads to time-consuming integrations when classical methods are used (typically plane or spherical waves expansions). To solve this problem, specially at high frequencies, phase-space methods, which treat simultaneously spatial and spectral properties of fields, have been proposed [1]. These methods include windowed Fourier transform and wavelet transform.

In the context of aperture theory, the most often used phase space representation is the so-called Gabor representation [2]. This method is based on a particular discretized windowed Fourier transform. For radiation and scattering problems, the window is usually Gaussian since Gaussian windows are well suited to performing asymptotic approximations and generate beam propagators that are related to the conventional Gaussian beams. However, Gabor method seems to suffer from inherent limitations. The objective of the present work is to propose another windowed Fourier transform decomposition in order to overcome these limitations.

The Gabor decomposition will be illustrated in the case of a two dimensional configuration. This method is based on the following decomposition of the aperture distribution :

$$u_0(x) = \sum_{m,n} A_{mn} w(x - mL_0) e^{in\Omega_0 x}$$

w(x) is a Gaussian window, L_0 and Ω_0 are respectively the spatial and spectral shifts and $L_0\Omega_0 = 2\pi$. The Gabor coefficients A_{mn} are obtained through a discrete windowed Fourier transform of the aperture distribution, where the window function is biorthogonal to w(x). Indeed, it has been shown that the Gabor expansion is unstable [3]. This is probably the reason why the choice of the width of the Gaussian window greatly influences the final results [2] [4].

The decomposition we propose instead is based on the mathematical concept of *frame* [3]. We replace the condition $L_0\Omega_0 = 2\pi$ by $L_0\Omega_0 < 2\pi$, which leads to a different calculation algorithm for the expansion coefficients.

This method is used together with asymptotic approximations of the beam propagators to determine radiated or scattered fields [1] [2]. The numerical results will be analyzed and compared to reference results obtained through a continuous decomposition and to results obtained through the Gabor representation.

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The Effect of the First Sidelobes of the Feed Antenna on the Radiation Pattern of the 2D Circular Reflector Antenna System

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Reflector antennas are commonly used antenna types in the telecommunication systems. Reflectors are generally parabolic and if they are infinity in dimensions (i.e no edges) their radiation will be in single direction. However, in practice reflectors have finite dimensions and the edges at the reflectors causes the diffraction. Therefore, they have a radiation pattern. On the other hand, reflector antenna systems have a feed antenna with a radiation pattern (i.e. main beam and sidelobes). Main beam almost gaussian in shape around the maximum point and sidelobes below the main beam approximately -20 dB or less then this value. In this work feed antenna pattern is simulated by complex source approach. This is performed by the addition of complex part to the position of the omnidirectionel feed antenna. Hence, the feed antenna pattern in the complex position radiates a gaussian type directive field. In the previous work of [1], the radiation from the 2D circular reflectors with a feed that has no sidelobes are analyzed. This analysis is performed by complex source-dual series approach.

In this study, we analyzed the similar type circular reflector antenna by the complex source-dual series approach. But in this case, feed antenna has first sidelobes at 60° from the feed position. Radiation patterns are obtained and compared for the sidelobe case and no sidelobe case for the same edge illuminations.

The approach combines the complex source method and the dual series treatment of the scattering from the reflector antenna. Dual series equations are obtained by Helmholtz Equation and appropriate boundary conditions. One can then directly solve these dual series equations by using well-known numerical techniques such as method of moments. Instead, in the present approach, these dual series equations are regularized by the Riemann-Hilbert problem technique and the final matrix equation is obtained as a Fredholm Equation of 2nd kind. Therefore, the convergence of the solution is guaranteed. In addition, un like the usual method of moments, the results can be obtained with any desired accuracy.

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Radiation Fields of a Complex Source in a Circular Cylindrical Radome with Metal Grating

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Radiation fields of a line source enclosed by a circular dielectric radome with metal grating consisting of an array of thin lossy strips are analyzed. We focused on studying the variations of the directivity of a source beam with respect to the beam direction and found the possibility of damping these variations by an appropriate design of the radome.

The problem is first formulated for metal gratings in free space and then extended to metal-dielectric gratings. Complex line sources are considered to simulate directed beam fields used in practice. The fields on the interior and exterior sides of the radome are represented by modal cylindrical waves. Transparency boundary conditions of a new generalized form provided in literature, are applied and manipulated according to our geometry to relate the outer fields to the inner ones, and the numerical solution of the problem is obtained. Although these boundary conditions were initially derived for planar sheets, the numerical data obtained justify strongly the validity of our method for circular geometry as well.

Results for the far-field patterns and the directivity are calculated for various structures as functions of the beam orientation, the strip width and the number of the strips for both metal gratings surrounded by vacuum and metal-dielectric gratings. Also the dependence of the directivity on the thickness of the dielectric layer is investigated. For the validation of the method, the results were compared with the ones available for some special cases.

According to our numerical data, the distortion of the main beam increases and the directivity decreases with increasing the number of strips and the strip width for the case of metal gratings in free space. The directivity reveals a kind of resonant behavior as a function of the strip width d when the latter is about a multiple of the half wavelength in free space, d ~= n lambda / 2 .

The directivity shows wide variations as a function of the beam direction. However, by a proper insertion of a dielectric layer between the metal strips, these variations are reduced considerably especially when a perfect dielectric of half wavelength thickness is inserted between the metal strips of width d < lambda / 2. This effect is observable with lossy metal strips and disappears with perfectly conducting ones.

Small Flat Multi-Panel Reconfigurable Reflector Antenna : Theoretical Investigation

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This paper presents results from theoretical investigation of a small flat multi-panel reconfigurable reflector antenna. The beam shape of this antenna can be reconfigured to counter the effects due to changing electromagnetic environment in terrestrial applications. The reconfigurability of the beam shape is achieved by changing the reflector surface. In this work the flat reflector has a circular shape, with its surface divided in a number concentric rings. Each ring is subdivided into a number of small circumferential panels. A single feed is placed at a position that ensures symmetrical illumination on the reflector surface. Each panel can be adjusted in order to alter its beam shape and direction.

The method of the calculation employed in analyzing the performance of this antenna is the physical optics technique. The reflector of the antenna considered here consists of N rings which each has M circumferential panels (NxM panels). The linearly polarized source is used as a feed. The frequency of operation is set to 4 GHz. The parameters of interest in this investigation are the number of panels, the rotation angle of each panel, the feed position, and the feed type. The ray approximation technique is used to aid adjustment of the beam shape by approximating the direction of ray bundles that can possibly form the desired beam shape or direction from each panel to find the rotation angle. The rotation angle of each panel is set to be less than the angle between the aperture plane tangent and the line joining each panel center and the feed position minus 10 degrees (80 degrees minus the angle between the antena axis and the line joining each panel center and the feed position).

It is found that the antenna beam width can be altered by changing the feed position. As the feed is moved away from the reflector surface, the produced beam become narrower. The number of panels affects the generation of the desired beam shape. It is interesting to note that there is an optimum number of panels that can ensure the success of beam shifting. In addition, it is observed that the feed should be located at a distance about 4-6 wavelengths away from the reflector surface in order to shift the beam towards desired direction. However, the beam shifting is limited to only 20 degrees from the boresight directions. This is found from the ray approximation technique. This beam shifting limitation does not depend upon the edge taper nor the feed type employed. To this end, it is interesting to point out that this antenna has disadvantage in terms of the cross-polarization level. It will increase as the panels is adjusted from the original angular position. Further investigation on the cross-polarization is to be carried out.

Scanning Dual Reflector Antenna with Rotating Curved Subreflector

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Communication applications antennas require directive beams. Paraboloidal reflector antennas can be employed, but limited beam scanning can be obtained from a point source by displacing the feed from the focus point due to the phase aberration introduced. Spherical or parabolic torus geometries produce wide-angle scanning with a single reflector and low illumination efficiency. Multifocal surfaces have a wide-angle scanning performance with better efficiency.

The new design method is based in the parabolic torus (different sections of the main reflector surface are illuminated for the scanned beams [1]) and the bifocal reflector (two tilted bifocal systems are combined [2-4]). The rotaitng curved subreflector redirects the beam coming from a unique feed into the main reflector surface and the variation in the illuminated area produces the beam scanning. Only one feed is required for scanning, yet the large reflector remains fixed.

If ð is the maximum scan angle for the antenna (XZ plane) and the subreflector rotating angle is b, the bifocal scan angle is a = q - b. The tilted bifocal system profiles with focal points symmetrically placed are designed by raytracing [3]. The three-dimensional extension is performed with a quadratic approximation (YZ plane profile) [4]. The second bifocal system, tilted an angle -b, is mirror symmetric to the first. The final main reflector is obtained combining sections of the main reflectors of these bifocal systems, tilted and joined smoothly, while the rotating subreflector is simply that of the bifocal system.

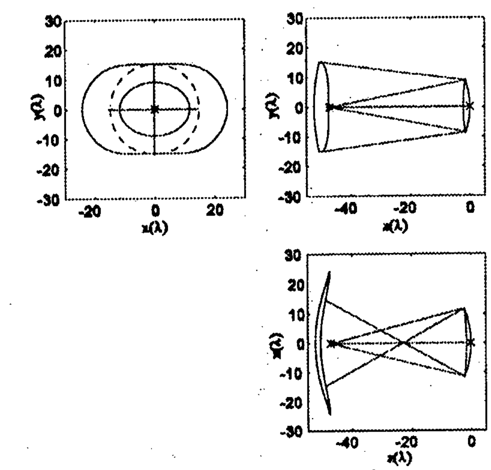

Fig. 1. Dual reflector antenna views

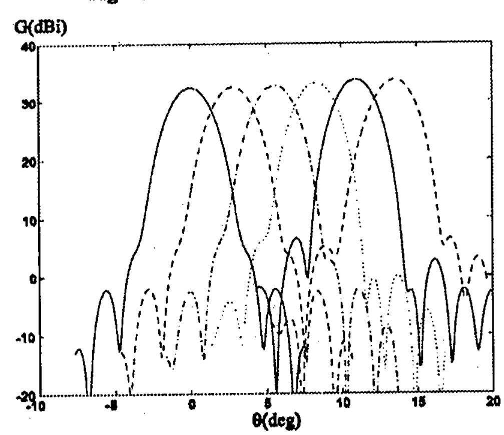

Fig. 2. Radiation pattern.

Fig.1 shows the antenna designed for 20(field of view (with a = 10(and b = 5°). The radiation pattern for a cos-q feed model is shown in Fig.2 The directivity (32.4dB to 33.2dB for the unscanned and scanned beams) and the side lobe level (27dB approx.) are practically constant along the field of view.

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Session G05
Tuesday, July 14, PM 13:40-15:20
Room M
Passive and Active Optical Waveguides

Chairs : Ch. Boisrobert, K. Ono

Multifunctional Two-Electrode Fabry-Perot Device

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Low-cost optical communication modules are essential in the aim to bring the optical fibre up to customer. Performances become secondary in front of cost and in this way, WDM communications can represent a suitable compromise, due to the lower cost of the driving electronics at reasonable transfer rates. Optoelectronic components such as tuneable laser sources, detectors and wavelength converters are also required to fill in cost requirements, and cheaper structures have been proposed [1].

Two-Electrode Fabry-Perot (TEFP) Buried Heterostructure (BH) lasers have demonstrated their potential in terms of tuning [2], and using an internal interference mechanism, their monomode behaviour, exhibiting a chirpless small-signal AM modulation. But this structure can also be used as amplifier, wavelength shifter, filter, and photodetector. Moreover, the behaviour can be improved with precisely positioning etchings along the cavity, and optimised with acting on structure parameters such as section lengths, the facet antireflection coating, and the interface reflectivity between two sections. The same simple structure can thus be optimised for the desired function.

The description of such components is usually based on field propagation and rate equations. This model leads to simple analytical solutions for mono- (or two-) section structures, but the size of the expressions increases rapidly with the number of sections, and becomes prohibitive. For our simulation, we use a condensed matrix form of field propagation description, extended to a 3x3 size, including spontaneous noise sources and the coupling into the resonant modes. This general-purpose approach (able to describe DFB and DBR lasers [3] is simple, and can support several levels of description of physical parameters such as gain, spontaneous emission and refractive index. Moreover, it allows a multimode treatment, and an expression of the linewidth can be derived.

We present theoretical characteristics of TEFP etched structures, varying the dimensions of the structure, reflection coefficients at the facets and at the interfaces, in function of the desired utility of the device. The etchings and other interfaces are treated as equivalent dirac-like singularities, following [4].

For a monomode tuneable laser source, constant power and constant wavelength contours about threshold are derived in function of the driving currents, showing an optimisation of the Side Mode Suppression Ratio for particular locations and reflectivity of the etchings. The sensitivity of the spectral properties to a lack of precision in the positioning of the etching is studied. The optimisation as filter and photodetector is also investigated, confirming the multifunctionality of the device.

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Coupled-Mode Analysis of Bent Three-Dimensional Optical Structures

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In recent years the dielectric optical waveguides constitute one of the major communication systems. Curved waveguides are one of the main building blocks of those systems. Thus the study of light transmission in various type of bent three-dimensional optical structures become important.

The numerical method proposed in this paper is devised to analyze the bent three dimensional optical structures with arbitrary shapes and refractive index profiles. It uses combination of the conformal mapping technique and coupled-mode theory with a series expansion [1].

To ensure this method for three-dimensional structures, it is applied to a uniformly bent single-mode three-layered optical fiber, i.e. standard telecommunication fiber in air. The bent fiber is described by longitudinally independent equivalent index profile [2]. The field of fundamental mode is given by an expansion on the modes of a known waveguide. As this known waveguide, we employ a two-layer (core/cladding) step-index optical fiber model because its modes can be analytically expressed and computed with a very high accuracy. To have a complete set of modes upon which any field may be expanded, one has to include the guided and radiation modes. In our case, however, we limit the expansion to a finite number of modes, which all are guided as the reference guide is largely multimode. The coupling coefficients for modes have a simple general form. The equations system is easily solved numerically by Runge-Kutta method.

The numerical simulations show that number of used modes can be decreased and consequently this reduces computation time. The coupled-mode analysis give field distributions in the bent section and transmitted power into the fundamental mode of the straight section, and accurately yielded the pure bend loss. The obtained results are in good agreement with other theories. [3], [4]. The further calculations will be carried on rectangular waveguides.

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2-Mode Design Theory for Symmetric Multi-Branch Optical Dividers

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Optical power dividers have found wide applications for guided wave devices in optical communication and optical data processing systems. Although many researches on Y-branch have been published, multi-branch waveguides have been received less attention [1]-[3].

Branch optical dividers consist of tapered structures, a tapered section and a branching section. If the tapered structure is substantially shallow, the mode conversion loss is negligible. This operational property is called adiabatic. The loss of devices consisting of tapered structure is essentially low. However, the same operational principle fixes the power dividing ratio of multi-branch optical dividers. Therefore, to alter the power dividing ratio and to keep the branch divider low loss, insertion of mode converter between tapered structure is preferable.

We propose a 2-mode design theory for symmetric multi-branch optical dividers with arbitrary power distribution among the outgoing waveguides. The mode transducer based on the 2-mode design theory consists of periodic section to convert the power from the fundamental mode to the 2nd order mode and a straight section to alter the relative phase between the two modes. The period is chosen as the length of beat wavelength of the two modes, since effective and selective mode conversion from the fundamental mode to the 2nd mode is preferable. The advantage of this configuration as a mode transducer comes from the possibility of controlling the relative amplitude and phase between the two modes independently. The mode converter based on the design theory is inserted between the tapered and branching sections to control the complex amplitudes of the fundamental and the 2nd order modes.

In this paper, numerical calculations are carried on the symmetric multi-branch planar optical dividers which connect a single-mode planar waveguide to 3, 4 or 5 waveguides with the same index distribution. Numerical results show that low loss 3- and 4-branch power dividers with arbitrary power dividing ratio and equal power division for 5-branch dividers are possible.

Low loss channel waveguides with rectangular core can be fabricated by the combination of flame hydrolysis deposition and reactive ion etching techniques [4]. The design method proposed in this paper can be directly applied to multi-branch optical dividers consisting of such waveguides.

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System Simulation of Digital Optoelectronic Circuit Detrimental Effects

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Optoelectronic emitter and receiver block performances are key points for the design and optimization of high bit rate (wide bandwidth) digital optical systems. These blocks are fabricated with hybrid or monolithic optoelectronic integrated circuits. In this communication, we present theoretical and experimental results of the emitter circuit misfunctioning on the system performances.

For 1.3 and 1.55 µm high bit rate digital systems, the emitter circuit is fabricated with a laser diode modulated by a III-V FET (HEMT)-based IC driver. Such an electron device suffers from detrimental effects penalizing the direct or external modulation of the laser diode [1]. The major effect is the drain lag. It corresponds to time-dependent drifts of the drain current due to high laser drive voltages. These effects are usually introduced by III-V materials and device structures. We deeply investigated this parasitic effect, on several generic III-V FET (HEMT) fabrication processes, keeping in mind the system application : two parameters, related to the device operation into system, the drain lag ratio and the current time constant drifts have been identified and characterized.

Then, these parameters have been injected into a system simulator, named COMSIS [2], which includes an optical library and provides the ability of quickly developing user models.

The study consists in three steps : Model definition, validation and simulation of an emission subsystem. The eye diagram is considered as the final system performance. Different models have been developed and implemented to include the drain lag effect, with more or less realistic results according to experiments.

Among the results, we must point out that the upper part of the frequency bandwidth is not affected but the lower part. This is detrimental for the optical system operation which carries information along the overall bandwith.

Detailed explanation and results will be presented and commented.

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[2] COMSIS is a patented software from IPSIS.

Femto Second Dynamic Characteristics of Integrated Optical Amplifiers Usin ER-Doped Garnet Film Wavequides

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Thin film Er-doped integrated optical amplifiers are regarded as very promising devices for the widely used communication and signal processing applications in the 1.53 mm wavelengh band. They have additional advantages such as compactness and low-noise characteristics when compared to fiber and semiconductor amplifiers. Also heavily doped amplifiers are possible to obtain high gain. Emphasis has been given so far on the steady-state response characteristics, and high gain amplifiers using Nd:YAG thin film waveguide amplifiers with gain up to 16 dB/cm have been reported by one of the author. Understanding of the dynamic characteristics of the integrated optic waveguide amplifiers is necessary when the input signal is modulated in various formats. In the present report, the dynamic amplification characteristics of Er-doped Garnet crystal integrated optical waveguide amplifiers, studied numerically based on time-dependent rate equations and mode evolution equations, are presented. In the case of Er doped laser amplifiers, pump wavelengths in the visible and near infrared lead to excited state absorption, which will affect the gain characteristics and has been included in the present study.

The dynamic response characteristics of integrated optical waveguide amplifiers, when the input signal to the amplifier is modulated in different formats, are numerically analyzed. The time dependent three-level laser rate equations and mode evolution equations are solved numerically using forward difference method. Steady state response of the Er doped Garnet crystal waveguide amplifiers have been analyzed in order to optimize the gain characteristics, which are further used in the dynamic response analysis. Accordingly, it is shown that a high gain of 20 dB/cm is possible to be achieved. Experimentally determined parameters such as waveguide loss, absorption and emission cross-sections have been used for the simulations.

Because of the slower gain dynamics of the Er doped Garnet waveguide amplifier medium, the longer singnal input pulses are observed to be distorted upon amplification. Very short pulses of pico- and femto-second duration are amplified without change in the pulse shape. Input pulses of square, Gaussian and Lorentian shapes have been considered for the numerical examples.

Session G06
Tuesday, July 14, PM 15:40-18:00
Room M
Electrodynamics of High Tc Superconductors

Organiser : G. P. Srivastava
Chairs : G. P. Srivastava, M. Pyee

Surface Impedance of High T_C Superconductors Using Traditional and Modified Phenomenological Models : an Overview

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The most of the microwave properties of superconductors can be understood in terms of surface impedance. Also, accurate calculation of surface impedance is an indispensable need in the analysis of many microwave devices using superconductors. The surface impedance was traditionally calculated using two fluid model [1] or BCS theory for conventional superconductors. Since the discovery of high T_c superconductors we have various types of materials having surface impedance behaving differently. There are few recent modified and new phenomenological models [2-5] trying to explain the surface impedance of new materials. In the present work, we compare the reults of various models with the traditional one in view of their application in the analysis and design of many microwave passive devices.

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Electrodynamic behavior of Ag-doped YBCO films grown by laser ablation

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Using laser ablation, we deposited a series of Ag (0, 2, 4, 6, 8, 10, 20 wt. %)-YBCO films on MgO (100) substrates. The films were deposited at 760°C and post-annealed at 500°C for 60 min. for the in situ superconducting growth. We characterized them by using scanning electron microscopy (SEM) and θ-2θ x-ray diffraction and rocking curve measurements, and measured their electrodynamic properties such as J_c and T_c by using a standard four probe *R-T* measurements. Morphological change of the grains with Ag-doping in the film was investigated by SEM. In addition, we prepared Ag(20 wt. %)-YBCO at 650°C with and without annealing and investigated the behavior of silver in the films. By energy dispersive spectroscopy and Auger electron spectroscopy (AES) no silver was observed in the films at 760°C while many silver droplets were found in the Ag (20 wt. %)-YBCO films grown at 650°C. AES study revealed that silver was localized near top surface and was evaporated during deposition at 760°C and in a successive post-deposition annealing at 500°C for 60 minutes. In this paper, we will report the electric transport properties of Ag-doped YBCO and the role of silver in the growth of superconducting YBCO film.

Analysis of HTS Microwave Planar Circuits : a General Computational Scheme

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This paper presents an outline of analysis of multilayered circuit structures for microwave application. Accurate evaluation of the characteristics of microwave and millimeter wave passive devices requires a fullwave approach. Recently there has been a growing interest in this area [1,2].

This paper first of all describes a computational scheme for the analysis of a general multilayered structure which may involve superconducting layer and strips. The superconducting layer is brought into analysis by incorporating the superconducting dielectric function. The standard method of application of the complex resistive boundary conditions to derive the electric field integral equation and its solution using a Ritz Galerkin technique is described and results of a certain specific cases are presented.

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Surface Resistance of Ag-doped $YBa_2Cu_3O_7$ Thin Films

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The surface resistance (R_s) of High Temperature Superconducting (HTS) thin films is much smaller than that of conventional metals up to the frequency of about 200 GHz. For good quality $YBa_2Cu_3O_7$ thin films, R_s is approximately equal to 0.4 mΩ at temperature of 77 K and frequency of 10 GHz. If a d - wave model of superconductivity is assumed, ten times smaller losses should be possible to achieve. That is why a lot of research is being done on development of deposition processes to obtain HTS films of smaller losses than currently available. One of the methods under investigation to decrease losses of HTS materials is by doping with silver [1-5]. Preliminary works show that silver doping improves the microstructure of the thin film by changing the orientation and size of superconducting grains in YBCO films. As a result the surface resistance decreases and the critical current density (J_c) increases. Therefore, the microwave properties can be improved without compromising other superconducting properties by Ag doping.

Pinto et al. [1] found that for an optimum doping of silver equal to 5%, the surface resistance reaches a minimum value. Kim et al. [2] also carried out the measurements on Ag doped films and they found that the J_c increases and R_s decreases with Ag doping. Losses of Ag doped YBCO thin films have been measured using microstrip method [1-3]. Therefore the presented results include losses due to patterning on the top of intrinsic losses of Ag doped YBCO films.

We have carried out systematic studies of surface resistance of silver doped HTS thin films using a more accurate measurement technique, namely the sapphire dielectric resonator. The advantage of this technique is that measured losses are only due to the intrinsic properties of the thin film superconductor. We are reporting results of $YBa_2Cu_3O_7$ thin films of thickness 450 nm on MgO substrates of thickness 0.5 mm, with Ag doping of 0%, 2%, 4%, 6%, 8%, 10% and 20%. The films were made using the pulsed laser deposition technique [2]. The measurements will carried out at 24.5 GHz at different microwave power levels. We have also studied the change in microstructure of the films due to different doping. The aim of our studies was to investigate methods to decrease R_s of YBCO films at microwave frequencies for applications in cellular and PCS base station filters.

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Theoretical Analysis of Superconducting Transition Temperature in Fullerides

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Superconductivity in fullerides-alkali doped fullerites C_{60}, is essentially due to the electron-phonon mechanism as has been unambiguously indicated by the large experimental isotope exponent, $\alpha = 0.3 \pm 0.06$, when 99% of ^{13}C replacement takes place in ^{12}C. The theoretical analysis of the recently observed temperature variation of specific heat in the range 0.2-300K of polycrystalline fullerite shows the presence of low energy intermolecular modes like anisotropic acoustic, librational, orientational diffusive and tunnelling, in addition to the energetic intermolecular modes, contribute to the specific heat only at high temperature. These modes (intramolecular), however, have been used to account for the observed superconductivity ; In the present investigation, the low energy modes (which are weighed strongly in the Eliashberg electron-phonon coupling constant, λ) have been incorporated to explain the superconducting transition temperature, T_c, in fullerides. It is found that these modes play an extremely important role not only in the determination of T_c but also in explaining the observed isotope exponent consistently. Futher, when only anisotropic acoustic modes are considered, the low value of T_c in intercalated graphite can also be explained.

Review of Different Techniques for Tuning Microstrip Circuits Based on SHTC thin Films

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At microwave frequencies, the resonant frequency depend on the effective dielectric constant and geometrical dimensions of the circuit.The resonant frequency of metallic circuits can therefore be tuned by changing these parameters or by introducing a variable capacity inside the circuit.

The intrinsic behaviour of superconductors thin films offers more possibilities of tuning circuits. A variation in temperature involve a slow variation of the resonant frequency then one can define a passive agility corresponding to an evolution of a parameter of the circuit of the environment.

An active agility can be obtained by means of an external excitation , without modifying the structure :

- The application of a magnetic field on a type II superconductor creates mixed state where vortices take place over the material. The coupling of the vortices with the microwave currents increases the penetration depth which induce a displacement of the resonant frequency.
- The illumination with an optical beam on a superconductor circuit induces two phenomenas that superpose ,the first is a thermal variation due to the radiation absorption in materials, and the other producing the pair breaking effect and the generation of quasi - particles. Then a displacement of the resonant frequency can be obtained.

Today , results have been obtained on resonators , filters and couplers and accordability due to a magnetic and thermal effect has been observed.

Modelling the electrodynamic response of composite superconducting structures in the mixed state

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A phenomenological model for the linear electrodynamic response of a type-II superconductor in the vortex state is described. Both effective mass anisotropy and tensor forces on vortices are included, so that anisotropic superconductors can be studied. A continuum model is developed which includes the coupling of all electrodynamic fields. The application of the theory to superconductor--dielectric structures provides a model for superconducting waveguides and transmission lines subject to magnetic field.

This paper presents a terse description of the linear electrodynamic response of a type-II superconductor in the mixed state subject to weak time-harmonic fields. Besides modelling the Meissner and vortex responses, the derived governing partial differential equations are sufficiently general to give either normal metal or dielectric material results in very special cases. The governing equations are outlined for an anisotropic superconductor, then specialized to a superconductor isotropic in both the Meissner and vortex responses. The application of the results to the electrical engineering problem of superconducting waveguides is described.

The model developed here provides generality in the consideration of coupled vortex dynamics. The phenomena of tensorial forces, pinning, flux flow, and flux creep can all be included by means of the complex-valued dynamic mobility. The full inclusion of displacement current effects gives the capability to model wave propagation. The application of the resulting theory to composite superconducting structures enables the computation of the dispersion relation and response functions such as the surface impedance and quality factor.

Session H03
Tuesday, July 14, PM 13:40-17:20
Room R02
Composite Material Modeling II
Workshop on Complex Media and Measurement Techniques
Chairs : Mac Phedran, A. Priou

Effects of a Finite Screening Length on the Absorption of Electromagnetic Waves

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When an electromagnetic wave impinges on a semiconductor or ionic conductor having a sizeable screening length,it induces diffusion currents in addition to the ohmic currents,so that the order of the field equations is higher than for a metal,and the effective permittivity is non-local. Local equations are recovered by introducing the charge density as an additional field. Furthermore at interfaces, an additional boundary condition supplements the metal - like ones, namely the lack of occurrence of a surface distribution of charges.For simple geometries and in low frequency regimes, the finiteness of the screening length may either enhance or reduce the absorption of an incident plane wave, depending on the parameters, and effects precluded for metals are predicted : extinction of the reflection by a plane wall, complete absorption of an electric multipolar wave by a sphere, disappearance of the scattering by a small sphere, vanishing of both reflection and transmission coefficients,or conversely large transparency for a slab. A thick piece of material may be cooled down by the wave near the interface and overheated deeper inside.

Bulk Conductivity of Two-Phase Composites with Randomly-Distributed Spheroidal Inclusions

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Historically, the manufacture of composite materials has progressed without the advantage of a detailed theoretical model capable of predicting the material properties. The availability of such a model would clearly assist in the design of such materials. Here, a method for predicting the bulk conductivity of a two-phase composite medium is presented. The medium consists of particles of conductivity $\alpha\sigma$ embedded in a polymer matrix of conductivity σ. The particles are represented as spheroids so that a wide variety of particle shapes can be considered. Flat disks, spheres and long fibres are limiting cases. Following an approach adopted by Sangani & Yao [1], the material is modelled as a periodic structure composed of identical cubic cells in which a number of particles are placed randomly. By allowing several different spheroidal particles to be distributed arbitrarily within a unit cell, a much wider range of configurations can be modelled than is possible with only one particle per unit cell [2,3].

While noting that a number of different transport coefficients can be calculated using the same mathematical method, the problem of electrical conduction is considered here. The Laplace equation is solved subject to the conditions that the electric potential gradient is a spatially periodic function along all three Cartesian co-ordinate axes (with period equal to the dimension of the cubic cell), and that the electric potential and the component of current density normal to any interfaces are continuous at all points in the composite. A solution is expressed in terms of an expansion in spheroidal harmonics whose coefficients are determined by application of the interface conditions. The resulting set of infinite linear equations can be suitably truncated and solved for particular values of the particle-matrix conductivity ratio, α.

For sufficiently low volume fraction of the particle phase (up to about 30%), satisfactory predictions of the bulk conductivity of two-phase composites can be made using simple analytical formulae which require relatively few parameters [4]. Only the particle volume fraction and the conductivities of the two phases are needed. For higher volume fractions, the detailed microstructure of the material becomes important in predicting the bulk conductivity. Here, microstructural effects are assessed by making predictions of bulk conductivity for various values of volume fraction of the particle phase and for certain distributions of particle size, aspect ratio and orientation.

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Frequency Behavior of Percolating Systems

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Percolation behavior in insulator/conductor mixtures has been the subject of much study for many years. The resistivity drop that occurs when the critical volume fraction (fc) of conducting particles is reached has been well documented. However, much more information can be derived from a percolating system if we look at its frequency behavior. In order to evaluate the effect of frequency, a technique called impedance spectroscopy is used.

In this technique, one measures the relationship between current, voltage and phase angle over a wide frequency range (most often between Hz - Mhz). This frequency range is especially useful for detecting microstructural features at all length scales and is especially sensitive to the presence of interfaces between dissimilar materials, as the charge carriers will tend to build up at the junction between a conducting material and an insulating material.

The frequency effect between two dissimilar materials is best described in terms of Maxwell-Wagner polarization in which the space charge build up gives rise to a relaxation phenomenon which has a characteristic relaxation time given by the conductivities and the permittivities of the two component phases and their nominal ratios (in terms of volume fraction, shape, size and distribution). When the two materials are very dissimilar, the electrical response may not give rise to a relaxation phenomenon but instead results in percolation behavior.

The McLachlan equation below, which combines effective media with percolation behavior, takes the form :

$$(V_i)\frac{\sigma_i^{1/s}-\sigma_m^{1/s}}{\sigma_i^{1/s}+(\frac{1}{fc}-1)\sigma_m^{1/s}}+(V_c)\frac{\sigma_c^{1/t}-\sigma_m^{1/t}}{\sigma_c^{1/t}+(\frac{1}{fc}-1)\sigma_m^{1/t}}=0$$

where σ_c , σ_i and σ_m are the conductivities of the conducting, the insulating phase and the composite and Vc and Vi are the volume fractions of the conducting and the insulating phase respectively and t and s are fitting parameters and fc is the critical volume fraction of the conducting phase. To evaluate the frequency response of model percolating systems, the conductivities given above were replaced by the complex conductivities and the complex permittivities and then they were converted to all the dielectric functions (electric modulus, impedance, dielectric loss, admittance).

By simulating compositions near the percolation threshold for a variety of conductivity and permittivity ratios of the two components, we have determined that the frequency at which the composite changes from insulating to conducting behavior depends on the t and s parameters.

Magneto-Optical Properties of Metal-Dielectric Composites with a Periodic Microstructure

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Very recently, the phenomenon of induced anisotropic dc magneto-transport in a composite conductor with a periodic microstructure was first predicted and studied theoretically and numerically [1], and then verified experimentally [2]. Here we discuss the possibility of observing analogous behavior in the ac electric permittivity of a metal-dielectric composite with a periodic microstructure in the presence of a strong magnetic field.

Using the Clausius-Mossotti-type approximation we first show that in a non-dilute metal-dielectric composite medium the magneto-plasma resonance and the cyclotron resonance depend upon the microstructure. Near such a resonance, it is possible to achieve large, essentially imaginary values for the ratio of the off-diagonal-to-diagonal electric permittivity tensor components, $\epsilon_{xy}/\epsilon_{xx}$, which is analogous to similar ratio of the resistivity tensor components, ρ_{xy}/ρ_{xx}, in the case of dc magneto-transport problem.

Motivated by this observation and by results of previous studies of dc magneto-transport in composite conductors, we then performed a numerical study of the ac magneto-electric properties of a particular metal-dielectric periodic composite structure which had two characteristic length scales, determined by the particular nonuniform distribution of the metallic inclusions. When the frequency is in the vicinity of one of the sharp resonances, there appears a strong dependence of the effective transverse electric permittivity, $\epsilon^{(e)}_{\perp}$, on both the magnitude and the direction of the applied static magnetic field, ${\bf B}$.

The various magneto-optical properties (including Faraday rotation, etc.) of such composites are considered. The possibility of observing these new effects in a suitably synthesized composite film is considered in detail. The parameter values needed in order to observe these effects can be realized, for instance, by using intrinsic (undoped) InAs as the dielectric host and Si-doped InAs rods as the metal inclusions. We hope that the results presented here will stimulate experimental studies aimed at verification of our predictions and continued exploration of the magneto-optical properties of such systems.

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Propagation Characteristics of Multiple-Scattered Polarised Light in Random Media

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Results are presented of a Monte-Carlo study of the influence of using polarising optics for imaging in a random scattering medium. The study considers a variety of single-ended illumination and imaging geometry's and is principally concerned with active illumination systems. The performance of both linear and circular polarisation states of illumination will be contrasted. The Monte-Carlo simulation tracks the propagation of the light through a multiply-scattering medium and rigorously calculates the Stokes vectors describing the polarisation state of each ray as it propagates. Results will be presented for three types of scattering particles that are distributed through the medium in a random fashion; these are spherical Rayleigh particles, non-spherical Rayleigh particles and spherical particles of finite size that are in the Mie scattering regime. The object to be imaged is treated as a planar diffuse reflector with variable absorption, and as such provides a model of a painted surface. Various polarisation properties of the object/target are considered; namely a target which preserves the incident polarisation state of the light it scatters, one that randomises the polarisation state and a target which acts as a dense multiple-scattering region where the degree of depolarisation is determined from the (exact) scattering properties of the particles. Results will be presented showing that the effectiveness of polarisation discrimination in active-illumination imaging systems are critically dependent on the scattering properties of the target to be imaged as well as those of the intervening medium itself.

The Design Principles and Measurement of Surface Wave Absorbing Materials

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Surface waves are waves which propagate along an interface of two different media without radiation [1]. Surface wave absorbing materials are used to reduce and redirect the power scattered by several classes of scatterer. The perfect electrical conductor (PEC) half-plane shown in Figure 1 is a generic scatterer which will be used to illustrate the theoretical and experimental techniques necessary for the development of optmized surface wave materials.

The PEC half-plane in Figure 1 is coated with a surface wave absorbing material and is illuminated by a TEM wave at near grazing incidence. The diffracted power at the principal discontinuity is reduced through absorption of the propagating surface wave mode; usually the fundamental electric mode. From a scattering viewpoint, the magnetic mode is often less important to grazing incidence TEM incident waves. The material properties of the surface wave absorber are chosen to optimise power absorption in one or more of the electric modes. However, for absorption to take place it is necessary for energy in the incident wave (normally a TEM wave) to be converted into the propagating surface wave mode. For the treated planar edge in Figure 1, mode conversion takes place at the discontinuity between the absorber and the half-plane closest to the source. The mode conversion site is a second discontinuity which can contribute to the power scattered by the treated half-plane. Surface wave absorption, mode conversion and diffraction at the two discontinuities all impinge on the design of surface wave absorbers. There are also secondary effects associated with half-plane scattering which affect further the performance of the absorber. Planewave absorbers are guaranteed to reduced scattering from planewave sources: no similar guarantee applies to the use of surface wave absorbing materials.

In [2], the authors introduced a new technique for characterizing the propagation properties of planar surface waves. This technique is extended to characterize multi-layer surface wave absorbers. Theoretical analysis of the design constraints described above is combined with the experimental technique described in [2] to investigate scattering reduction through the use of surface wave methods. Other techniques for reducing half-plane diffraction are also considered in the light of the surface wave results.

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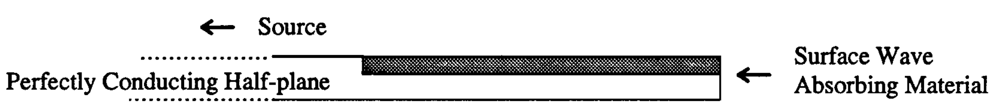

Figure 1 : A PEC half-plane treated with a surface wave absorber. The PEC half-plane is the cause of unwanted scattering in several areas including antennas and RCS.

Reflection Properties of Magneto-Optic Grating in Comparison with Magneto-Optic Ultrathin Films

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Multilayer systems containing magneto-optic media have been studied for several years. The attention is focused mostly on layered media consisting of alternating dielectric and metallic films where the magneto-optic metallic films have very low thickness. In this case, sometimes the metallic film during the deposition process doesn't form a continuous layer, but it exhibits the island structure. In other cases the film can be prepared in the form of strips.

We discussed a simple model based on the idea that in beginning the layer has a strip structure and during the deposition process, when the thickness is increasing, the width of the strips grows. In the end the strips form a continuous layer. The behaviour if such a transition is studied via the behaviour of the reflection of optical waves. The model calculations are in beginning performed using coupled wave analysis which allows us to describe the structure in the grating form and using Yeh's formalism for the description of the reflection from continuous layer. The task is to distinguish the strip structure from the film. The computations are performed for isotropic as well as for anisotropic film and grating structure. As to the grating structure, the duty cycle influence on the reflection coefficient is examined in detail. The case of anisotropic structure is assumed for transversal anisotropy. Because the thickness of the metallic film is in the range of nanometers and the assumed period is in the same range, the most energy in the reflection is carried by the zero mode order. From this point of view the strip grating structure can be treated as a ultrathin film described by effective material parameters.

The comparison of both cases is presented for two type of layered structure - grating layer on a substrate and grating structures placed between two buffer layers. In the case of the structure magnetized in transversal direction, the attention is paid to the TM-TM reflection coefficient, because only this one is influenced by the magnetization, whereas TE-TE reflection remains the same. The polarization conversion doesn't take place. For this situation, rather than the reflection coefficient itself, the difference between the coefficients calculated for two opposite orientation of the magnetization is studied. The anisotropy of the metallic film (or grating) is described by the relative permitivity tensor. The magneto-optic effect is taken to be linear in the terms of magnetization, the relative permeability is assumed to be the same as for the vacuum. Because of the approximative character of coupled wave analysis, the convergence of the computed quantities is checked for every considered case.

Fractal Superlattices: A Frequency Domain Approach

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Introduction

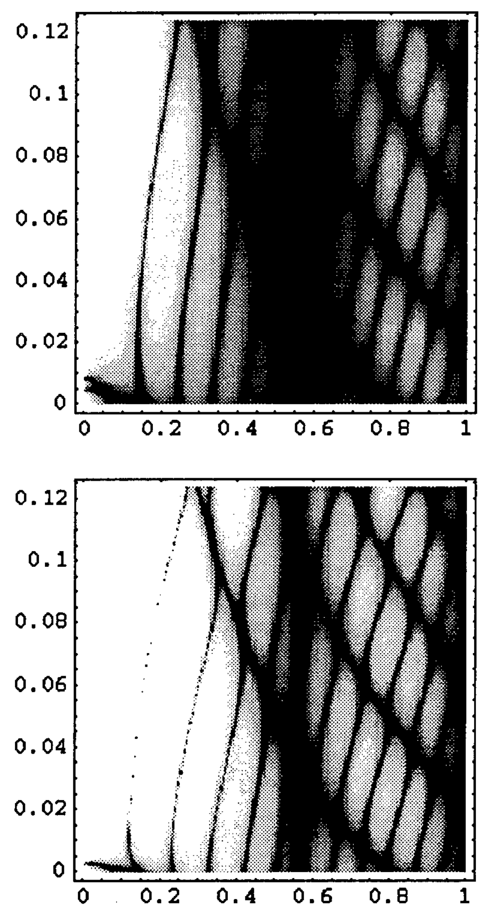
We investigate an area of *fractal electrodynamics* [D. L. Jaggard, "Fractal Electrodynamics: From Super Antennas to Superlattices," in *Fractals in Engineering,* J. Lèvey Vèhel, E. Lutton and C. Tricot, editors, Springer, Berlin (1997)] concerned with the reflection and transmission properties of polyadic fractal superlattices using a frequency-domain approach that takes into consideration variations in fractal dimension, lacunarity, number of gaps, stage of growth, and the angel of incidence. The salient features of the scattering are captured by families of reflection data we denote *twist plots.*

Fractals, Superlattices and Waves

A superlattice is a layered media with alternating layers containing different refractive indices. We find the scattering from a fractal superlattice using both recursion on the number of gaps in the superlattice and a second recursion on the stage of growth. This process yields a simple iterative expression for finding scattering data starting with the result of scattering from a single refractive slab.

As one example, on the right is shown the reflection twist plot for a fractal superlattice at the first stage of growth. Here the fractal dimension is $D = 3/4$, and waves are incident at oblique incidence with parallel polarization (upper) and perpendicular polarization (lower). The reflection is shown as a function of cosine of the incidence angle (horizontal) and normalized lacunarity (vertical). The null structure of these plots is amenable to simple physical interpretation. The upper plot displays the effect of the Brewster angle through the large vertical null in the region where the cosine of the incident angle is approximately equal to 0.6.

The use of such plots lends itself to the analysis of reflection from finely divided layers and the design and synthesis of microwave, millimeter wave and optical fractal filters. Applications to the inverse problem will be discussed.



Remote Characterization of Fractal Superlattices Using Wavelets

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In his pioneer work, B. B. Mandelbrot [1] discussed the limitations of Euclidean geometry to describe objects that exhibit scale-invariance properties and he introduced fractal geometry to solve the problem. The remote detection of fractal features of an object can be achieved from interrogation by an electromagnetic pulse [2]. One expects that scaling properties of the target can be extracted from some specific scaling behavior of its impulse response. The problem consists in determining a direct relation between fractal descriptors (such as fractal dimension, stage of growth and lacunarity) and the scattering data.

Here we interrogate *Cantor superlattices* by a Gaussian pulse. The reflection coefficient of these discrete multi-scale stratified structures is calculated on the basis of an efficient recursive computational technique called the *self-similarity method of computation* [3]. The impulse response is then directly deduced. Because of multiple reflections, this reflected signal exhibits wildly irregular variations and is viewed as a complex arrangement of singularities. In order to explore the relation between the spatial distribution of such singularities and the fractal characteristics of the interrogated superlattices, we use the *wavelet transform* [4-5].

From the skeleton of wavelet-transform modulus-maxima, we detect singularities in the impulse response that are distributed on a Cantor set, that is, on the same fractal set which governs the distribution of layers. A hierarchical structure clearly emerges at large scales and makes apparent the iterative process underlying the construction rule of the interrogated superlattices. The behavior across scales of such hierarchical structure allows us to extract the fractal dimension from the reflection data. The circumstances under which the hierarchical structure may be broken are discussed and the domain of validity of the present approach is estimated.

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Group Theoretical Approach to Complex and Composite Media Description

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Different complex media have been intensively investigated during the last 10-20 years due to many their potential applications. One of the possible representations of the constitutive relations for the media is : $D=[\varepsilon]E+[\xi]H,\ B=[\zeta]E+[\mu]H$. Under space-time symmetry of the media, the number of independent parameters is reduced. Here we suggest to treat the linear media using group-theoretical methods.

In the absence of external perturbations, the isotropic homogeneous media are described by two point continuos symmetry groups, namely K_h and K. The continuous group K_h is highest possible one and it corresponds to the symmetry of sphere with the planes of symmetry. The group K, on the other hand, may be represented by a sphere without planes of symmetry with all the diameters twisted through an equal angle in one direction. The isotropic chiral medium has such a symmetry. Any external field (for example, de magnetic one) or internal inclusions in the media K and K_h may be considered as a perturbation. These perturbations have different nature and symmetry. They may change the initial symmetry K_h and K. The perturbations can be described by the tensors of the second, first or zero rank.

It is shown in this work that all together we may consider 57 magnetic and nonmagnetic groups (continuous and discrete) which describe constitutive tensors of the symmetrical media. In order to find the structure of the constitutive tensors we use the approach developed in IEEE Trans., 1997, MTT-45, (3), pp.394-401 for em N-ports. For this purpose, several types of communication relations are used. They are obtained from the laws of the tensor coordinate transformations for the case of gyrotropic symmetry and for the case of gyrotropic antisymmetry. The commutation relations express the invariance of the medium under symmetry transformations. Using the suggested approach we may solve two kind of problems:

1. Determination of the constitutive tensors for a given symmetrical medium.
2. Determination of the complete nomenclature of the nonmagnetic and magnetic media constitutive tensors using the 57 groups.

We may notice high generality of the suggested approach : it uses only symmetry of the media under linearity restriction. The results of the paper may be useful in the problems of synthesis of new materials and for investigation of their properties. Some examples of application of the theory are given.

J. I. P. R. 4 - Session I03
Tuesday, July 14, PM 13:40-17:20
Room 200
POL-SAR Image Processing

Organiser : J.S. Lee

Chairs : J.S. Lee and T.L. Ainsworth

POL-SAR speckle filtering and terrain classification – an overview

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Speckle appearing in SAR images is due to the coherent interference of waves reflected from many elementary scatterers. Polarimetric SAR responses can be considered as the interaction of three correlated coherent interference processes for HH, HV and VV polarizations. Speckle noise not only appeared in the three intensity images, but also in the complex cross-product terms. Speckle complicates the image interpretation problem by reducing the accuracy of image segmentation and classification. In this paper, polarimetric SAR speckle filtering algorithms and terrain classification methods will be reviewed and compared.

Polarimetric SAR speckle filtering has been developed using several approaches. *Novak and Burl* (1990) derived the polarimetric whitening filter by optimally combining all elements of the polarimetric covariance matrix to produce a single speckle reduced image. *Lee et al* (1991) proposed two algorithms that produced speckle reduced HH, VV and HV images by using a multiplicative noise model and minimizing the mean square error. The off-diagonal terms of the covariance matrix were not filtered. *Goze and Lopes* (1993) generalized this approach to include all elements of the covariance matrix for one-look imagery. *Lopes and Sery* (1997) developed several filters to account for the texture variation using a product model. Theoretically, after applying these filters, HH, HV and VV become totally correlated, and cross-talk between polarization channels could be a problem. To avoid cross-talk and to preserve polarimetric information, *Lee et al.* (1997) proposed an algorithm that filters all elements of the covariance matrix equally but independently. The performance of some of these filters will be compared.

Terrain classification is an important application. Many algorithms have been developed for supervised and unsupervised terrain classification. Supervised classifications that based on statistical distributions (*Lee et al. 1994*), polarization contrast (*Lemoine and De Grandi, 1994*) will be reviewed and compared. Other algorithms based on fuzzy logic and neural network will be discussed. For unsupervised classification, approaches using scattering mechanisms (*van Zyl, 1989*) and target decomposition (*Cloude and Pottier, 1997*) have shown interesting results. They will be compared. Finally, the impact of speckle filtering on terrain and crop classification is illustrated using multi-frequency polarimetric data.

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Interpretation of High Resolution Polarimetric SAR Data

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As a first step towards automatic classification of high resolution SAR (Synthetic Aperture Radar) data, a manual inspection and interpretation of the data is usually necessary in order to develop understanding and optimize feature extraction procedures, automatic algorithms, etc. Efficient techniques for visualization of the data are therefore required. A frequently used way to visualize polarimetric imaging data is to generate images where three components are used to modulate the three basic colors: red, green, and blue. The most straight-forward approach is to simply use the magnitudes of the three complex elements of the Sinclair matrix, e.g., HH, HV, and VV, which may efficiently reveal scatterers generating predominantly horizontally, vertically, or cross-polarized fields. The phase relations between the various elements are, however, not usually included in this representation, but can be represented in other images, modulating the colors by the phase difference between different channels.

The question naturally arises, how one can best visualize and interpret the information contents of a given data set, and how it can best be handled by automatic procedures. The paper deals with various such methods. In particular, the role of polarimetric decomposition techniques will be considered, and special attention will be given to interpretations in terms of actual physical scattering mechanisms. Data recently acquired with the Danish EMISAR system, a high-resolution, fully polarimetric synthetic aperture radar (POL-SAR), will be used to illustrate the techniques under consideration.

High-resolution Polarimetric SAR for Littoral Remote Sensing

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Coastal regions provide intricate and complex interpretation problems for remotely sensed imagery. Typical littoral scenes include a range of topographic features, land use and vegetation types, as well as, the relatively low power return from water surface features. Fully polarimetric SAR imagery, *i.e.* HH, HV, VV and VH complex data, permits a richer understanding of littoral scenes than either single-polarization or detected, multiple-polarization images allow. This additional information arises not from the power returned in each channel, but rather from phase differences, power ratios and correlations among the complex radar returns.

Cross-polarization return arises from azimuthal asymmetries in the scene. Slope in the along-track direction, scatterer orientation and scatterer distribution within resolution cells produce HV and VH returns. Often with high-resolution SAR there is a single dominant scatterer per resolution cell. The scattering entropy offers a convenient means to test for a dominant scattering mechanism. In this case, the HV and VH returns depend primarily upon scatterer orientation and local azimuthal slope rather than the distribution of multiple scatterers. Application of sub-aperture processing produces a set of images each employing only a fraction of the total phase history data. These images have reduced spatial resolution; however, they display a time series of the imaged scene and highlight the look-angle dependence of the polarimetric response. This additional information can be employed to more precisely classify both man-made and moving features.

Fully polarimetric complex radar imagery permits incorporation of statistical correlations between various channels, polarimetric synthesis, polarimetric decomposition and sub-aperture processing into the image analysis. Together these techniques can selectively enhance particular features, identify the character of the radar scatterers, detect moving features, determine look-angle dependencies and generally provide a more detailed and precise classification of the imaged scene.

Danish EMISAR C- and L-band full polarimetric imagery of the Storebælt coastal area is used to illustrate these methods. In particular, polarimetric decomposition, polarimetric synthesis, and statistical correlations will highlight azimuthal slope determination, coastline detection and both land and sea surface feature analysis. Comparison to EMISAR data degraded to match the ~25 meter SIR-C/X-SAR resolution will show the advantages of high-resolution SAR imagery.

What Eigenvalues and Eigenvectors Can Offer in Decompodition of Polarimetric Covariance Matrix

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The classification of synthetic aperture radar (SAR) images based on the information provided by individual pixels cannot generally give satisfactory results due to speckle resulting from coherent processing. In order to obtain reliable and satisfactory results, the classification must be based on the statistics of clusters rather than individual pixels. Segmentation segments an image into disjoined regions corresponding to objects, or parts of objects that differ from their surroundings, and thus enables the futher classification to be performed based on the information provided by clusters. The procedure of segmentation is, therefore, very fundamental for many tasks of object-oriented processing and recognition.

Being shown to be an accurate compact representation for radar images, the Gaussian Markov random field model (gmrf) is used in the paper for segmentation. Segmentation using GMRF model segments objects based on the region information about not only up to the second order statistics but also the spatial ralationships. Other techniques, including wavelet transforms and the watershaed method are also incorporated to achieve the goal. Initial segmentation is obtained using wavelet transform techniques and the watershed method. Final segmentation is achieved by iterattions of merging those adjacent segments belonging tothe same cluster using the GMRF model analysis. Unsupervised classification is then performed for the segment clusters. The model thus considers two clusters to be different classes if one or more than one of the following conditions is true :

1. The first order statistics (the means for a single channel image ort he mean vectors for a multi-channel image) are different ;

2. The second order statistics (the variances for a single channel image or the covariance matrices for a multi-channel image) are different ; and

3. The spatial textures are different.

Since the classification is based on the segmented imagery, segments (a group of uniformed pixels) provide reliable statistics such as mean or mean vector, standard deviation or covariance matrix, and texture characteristis such as neighboring coefficients. It can, therefore, be expected that the accuracy of the classification is greatly improved.

Terrain DEM Extraction and Azimuthal-Slope Corrections Using Polarimetric SAR Data

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A technique using polarimetric SAR has been developed which is capable of directly estimating terrain surface slopes in the along-track (or azimuthal) direction. The method involves measuring the terrain-induced shift in orientation angle of the maximum in the co-pol polarimetric signature. After a geometric transformation, this shift is related to the actual terrain slope. The technique has been used to measure slopes and derive elevations for both open and forested terrain. Recent investigations have indicated that these slopes may also be measured in a circular-pol basis using the phase terms present in the off-diagonal terms of the covariance matrix. These slope-estimation methods permit separation of SAR backscatter originating from features of interest - and that caused purely by terrain slope effects.

Single-pass NASA/JPL AIRSAR data and the signature-maximum technique have been used to produce sets of azimuthal slope profiles spaced throughout the SAR range direction. These profiles can then be integrated to produce a digital elevation model (DEM) for the entire scene. Elevation tie-points must be known for each profile. This need for tie-points is a limitation on the technique when single-pass data is used. The required number of tie-points can, however, be reduced to just one if orthogonal, or quasi-orthogonal, two-pass images are utilized which cover the same terrain area. Terrain slopes in both the azimuth and range directions can be measured for all pixels within the common area by utilizing the one-pass slope algorithm for each pass. The topography can then be reconstructed by a weighted least-squares method and Poisson equation solution similar to that used in interferometric SAR phase unwrapping. Analysis of terrain slope/elevation orthogonal-pass polarimetric SAR images will be presented for desert terrain in Death Valley National Monument, California.

Techniques used to estimate surface roughness and soil moisture from SAR data are adversely affected when the surface topography is other than flat. An algorithm has been developed and tested to compensate for the polarimetric effects of azimuthal terrain slopes. The technique works for imaged areas having significant azimuthal symmetry. This condition is often satisfied in open-terrain and for many agricultural fields. If polarimetric SAR data is available in orthogonal look directions then the polarimetric effects of topographic slopes may be reduced in these directions for the entire scene.

Unsupervised Classification of Polarimetric SAR Images by Applying Target Decomposition and Complex Wishart Distribution

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In this paper, we propose a new method for unsupervised classification of terrain types and man-made objects using polarimetric SAR data. This technique is a combination of the unsupervised classification based on the polarimetric target decomposition (*Cloude and Pottier,* 1997) and the maximum likelihood classifier based on the complex Wishart distribution for the polarimetric covariance matrix (*Lee et al.,* 1994). The effectiveness of this algorithm is demonstrated using JPL/AIRSAR and SIR-C polarimetric SAR images.

[1] proposed an unsupervised classification algorithm based on the medium's scattering mechanisms in the entropy, H, and α angle plane. The α angle corresponds to the variation from surface scattering ($\alpha = 0°$) to dipole scattering ($\alpha = 45°$) to double bounce scattering from conductive surfaces ($\alpha = 90°$). The entropy represents the randomness of scattering mechanisms. The classification boundaries that divide the H-α plane into 8 classes are not based on the clusters formed by the polarimetric data under consideration. In most cases, clusters are not distinct due to speckle, and clusters may not confined in the region defined by the boundaries. Furthermore, the absolute amplitude, and other parameters are not included in the classification.

The maximum likelihood classifier for polarimetric SAR is based on the covariance matrix that has a complex Wishart distribution. [2] derived a distance measure that has been shown effective in terrain and sea ice classification. However, this algorithm is a supervised algorithm. Training sets have to be selected in advance.

We propose to use the [1] method to initially classify the polarimetric SAR image. The initial classification map serves as training sets for classification based on the Wishart distribution. The classified results are then used as training sets for the next iteration. Significant improvement in each iteration has been observed. The iteration ends, when the number of pixels switching classes becomes smaller than a predetermined number. The class centers in the H-α plane are moved after the first and each iteration. The class boundaries become indistinct with considerable overlap. The final class centers in H-α plane are useful for interpretation by scattering mechanism. To classify the same objects with different orientations, the orientation dependence is removed from the coherence matrix, and then the Wishart classification is then applied. The advantage of this method is in its effectiveness in automated classification, and in providing interpretation based on scattering mechanism for each pixel.

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POL-InSar imaging and applications to Geo/Eco-Environmental Stress Change Monotoring

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During the past decade, Radar Polarimetry has established itself as a mature science and advanced technology in high resolution POL-SAR imaging, image target characterization and selective image feature extraction. More recently, with the addition of single platform dual antenna interferometers, digital elevation mapping (DEM) was made possible which though can be recovered in most cases equally well from standard fully polarimetric POL-SAR image data utilizing the Schuler purely polarimetric DEM algorithms not requiring an interferometer.

However, in order to be able to fully describe direction-sensitive environmental stress changes, it is necessary to rapidly advance repeat-pass (RP) fully polarimetric (POL : Scattering Matrix) Differential (D) Interferometric (In) SAR imaging systems (RP-POL-D-InSAR) which have emerged with the successful SIR-C/X-SAR Missions 1 (1994 April) / 2 (1994 October). In pursuing this goal, Shane R. Cloude in addition to introducing the Polarimetric Entropy / Anisotropy Method together with Eric Pottier, more recently achieved another milestone by introducing the Polarimetric-Interferometric Phase Coherence Optimization (PIPCO) procedure together with Kostas P. Papathanassiou.

This PIPCO procedure is verified in this paper by utilizing an ideally matching repeat-pass pair of the recent SIR-C/X-SAR Mission 2, Tien-Shan Tracks within the Russian Academy of Sciences, Siberian Division, Buriat Natural Science Center (RAS-SD-BNSC) SE Baikal Lake, Selenga Delta (Kabansk-Kudara-Oymur : N52.16°, E106.67°) Geo-environmental Sanctuary, the 'Kudara Polygon' for environmental information and vegetative groundtruth data over the past several decades. This tectonically highly active region lies within the Mis-Asian Baikal Tectonic Rift Zone of the Hövsögöl-Baikal Lakes Basin which was recently declared as a World Heritage Site.

Speckle Well Modeled by Mellin Transform

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Multiplicative noise can be modeled with the help of Mellin Transform : this few spread mathematical transform deals with a causal signal (i.e. with a left bounded support) so that it is possible both to exhibit a "Mellin convolution" acting in the Mellin space as a product, and to use its inversion properties (the inverse Mellin transform). Speckle can be viewed as a multiplicative noise if the assumption of decorrelation is verified. It is why Mellin transform has been succesfully applied to SAR images in order to take into account texture laws of the scene : several examples have been developped in [1] yielding easily the analytical speckle laws in the case of Pearson model based texture laws.

This analytical approach, which proves the strongness of the method, is limitated by the severe hypothesis on texture laws, even if these hypothesis can be experimentally justified. It is why we propose in this paper to deal with numerical applications of the Mellin transform in order to identify texture laws. Classical methods are generally based on the computation of moments in order to parameter the law : yet it is well known the computation of high moments is corrupted by the smallness of the test basis. If these moments correspond actually to Mellin transform for values on the real axis of the Mellin space, we can also take into account Mellin transform for imaginary values in the Mellin space (as it is needed for the inverse Mellin transform).

Two methods can be applied when speckle laws are known (either analytically or experimentally). The first one consists in a numerical Mellin deconvolution based on an à la Wiener scheme : in this case we can exhibit the exact trend of the texture law. The second one consists in the characterisation of the mixture law by a limited set of Mellin transform values for complex values in the Mellin space so that classification tools can be succesfully used. These two approaches will be illustrated on SAR images for various scenes and various sensors.

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Session J03
Tuesday, July 14, PM 13:40-17:00
Room 450
Microwave Remote Sensing of Snow and Ice

Organiser : H. Rott
Chairs : H. Rott, C. Maetzler

Microwave Emission Model of a Layered Snowpack

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The growth and decay of the natural snowcover leads to characteristic stratification. The effects of snow metamorphosis typically cause the snow grain size, shape, density, and liquid water content to vary from one layer to another. Ground based measurements have shown that the radiometric properties of snow are strongly affected by these parameters. However, to our knowledge no reliable emission model for multilayered snow has been published.

In our model, covering the frequency range from 5 to 100 GHz, the snowcover is considered as a stack of horizontal layers. Each layer is characterized by thickness, correlation length, density, liquid water content and temperature. The layer interfaces are assumed as planar. In order to distinguish between the internal scattering and the reflections at the interfaces, a simple sandwich model, based on a radiative transfer, is used. Internal volume scattering is accounted for by a two-flux model (up and down welling streams) derived from a six-flux approach (fluxes in all space directions). However, the absorption and scattering coefficients are functions of the six-flux parameters. The absorption coefficient can be obtained from density, frequency and temperature, and the scattering coefficient depends on the correlation length, density and frequency [1].

Comparison of the model results with snow-slab measurements shows good agreement. Compared with independent data of natural snowpacks we obtain good agreement between the computed and measured emissivity at vertical polarization. At horizontal polarization the emissivity is sensitive to the existence and properties of thin horizontal layers. A promising use of the model are sensitivity studies to investigate the microwave behavior of snow.

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Microwave Emission Model of Layered Snowpacks Applied to Melt-refreeze Cycles

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The Microwave Emission Model of Layered Snowpacks (MEMLS) developed at the University of Bern [1], [2] was originally developed for dry winter snow. In a further step we extended the model to include both wet and refrozen snow. For this purpose we used data obtained from surface-based microwave experiments made on alpine snowpacks at linear h- and v-polarization at frequencies of 4.9, 10.4, 21, 35 and 94 GHz. The data include situations of wet snow of variable liquid-water content, formation of refrozen (i.e. dry) crusts on wet snow, starting from the surface to depths of more than 20 cm, simple, homogeneous snow layers, packs with strongly layered structure, some containing many ice lenses. The observations show very strong frequency dependencies of emissivity (from 0.4 to 1) and brightness temperature with variable polarization response.

The absorption coefficient of dry snow has been extended to include wet snow, based on measured dielectric properties, and the scattering coefficient has been derived from the distorted Born Approximation of freely arranged grains, using an exponential correlation function [3]. We will illustrate how the microwave emission model can handle the different situations over the wide frequency range. The model turns out to be useful for testing the sensitivity of any snowpack parameter on the observable radiation. The results indicate the importance of the multi-layer approach for describing polarization, and multiple scattering to obtain the low emissivity observed at the higher frequencies.

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The Use of 85GHz SSM/I Data for Snow Parameter Estimation in the SNOW-TOOLS Project

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In the microwave region of the electro-magnetic spectrum, there exist several window regions that have been exploited for Earth observation using the SSM/I.

The 85GHz data from the SSM/I have the best spatial resolution and potential detection of shallow and wet snow of all the frequencies, but are limited by atmospheric opacity, saturation of response to deep snow, and are affected by significant forest cover. The most common approach to snow parameter estimation using the SSM/I is by using a combination of frequencies and to apply a space-independent approach. This limits the spatial resolution of the product, and the sensitivity to surface conditions and certain snow types, but it has shown success globally for large, continental snowpacks.

By using the 85GHz data alone, a better resolution product with greater sensitivity to snow cover can be obtained. To achieve this, global data SSM/I have been analyzed over several snow seasons and statistical information has been used to segment the data based upon the characteristics of the snow cover signature at 85GHz into grouped signature units (GSU). From this analysis, methods to estimate snow parameters have been developed within each GSU. This allows the characteristic signature of the surface (a combination of the soil, vegetation, water content etc) to be incorporated into the method and removed from the data as background noise.

The use of extensive snow course data from the Former Soviet Union has allowed a comparison between an 85GHz, single frequency algorithm and existing multi-channel snow parameter algorithms. The snow courses include information on snow depth, density, crusting, site vegetation and snow base conditions, and this has been used to compare surface conditions with the SSM/I response. The identification of snow volume with better resolution and greater regional response will aid the understanding of how regional climates may be changing and how snow hydrology can be more fully exploited for energy production.

Image Fusion Techniques Using SAR and EO Imagery for Snow Cover Mapping in the Swiss Alps

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Snow cover variations significantly influence the hydrological circulation. Remote sensing data and related techniques offer the opportunity to continuously monitor the snow cover over large areas. Results of snow cover mapping and water equivalent estimation showed the usefulness of electro-optical (EO) data over large alpine basins. However, the use of optical satellite sensors can lead to lack of information, due to bad weather conditions. To overcome this problem interpolations to bridge the missing link between consecutive satellite images are required. Another possibility is to rely on radar sensors. Studies based solely on the use of single frequency, single polarization synthetic aperture radar (SAR) data could demonstrate that a monitoring of the snow melting process is feasible over a longterm period. Furthermore, using multifrequency polarimetric radar data, snow water equivalence, even in dry snow conditions, could be estimated. Analyzing advantages and disadvantages of the use of EO or SAR sensors, it can be concluded that EO data are more suitable for snow cover mapping purposes. On the other hand SAR systems are absolute necessary to retrieve certain snow parameters and to monitor the melting process. The goal of this work is to take advantage of the synergism of EO and SAR system using data fusion techniques, and to monitor the melting process over large mountainous areas. The completion of the first objective consists in a rigorous calibration of the remote sensing data in respect to the geometry and the radiometry using digital elevation models and sensors orbital data. While in optical imageries illumination and atmospheric corrections are additionally considered, a fully thematic information of SAR data can only be achieved applying the optimal resolution approach (ORA). In a further step, EO and SAR data will be fused pixel by pixel, using a Bayesian formulation, in order to reduce misclassifications. Based on a statistical classification the method incorporates a priori information (single-source snow classification, meteorological data, and ground measurements) on the likelihood of changes between the acquisition of the images to be fused. A framework based on Bayesian formulation is proposed. First, a simple fusion model is applied, and then the basic model is extended to take into account the temporal attributes between data sources acquired at different dates. The method decreases the misclassification significantly. In this study ERS SAR and Landsat Thematic Mapper TM data as well as Radarsat ScanSAR and NOAA AVHRR data are used. Results of snow cover mapping and monitoring over a whole melting period are presented. A testsite located in Eastern Switzerland covering 1200km^2 and representing altitudes from 600msl up to 3200msl is investigated with ERS and TM data. Using ScanSAR and AVHRR data main parts of Swiss Alps (160000km^2) are covered for this project.

Study of Snowpack Conditions Limiting Application of the Developed SAR Algorithms for Water Equivalent and Wet Snow Mapping from Observed and Simulated ERS-1 and Radarsat Backscattering Coefficients

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With SAR sensors in orbit, beginning with ERS-1 and now ERS-2 and RADARSAT, algorithms allowing estimation of the areal distribution of the water equivalent of snowpacks in dry snow conditions and wet snow mapping have been developed over the past years.

In the case of dry snow conditions, the algorithm works best with snowpacks smaller than 1 m without ice or refrozen layers. Also, the surface ground layer should be frozen and the distribution of ground surface temperatures should be related to the characteristic of the above snowpack. What happens to the accuracy of the algorithm as ice or refrozen layers appear in the snowpack? Is there a maximum depth over which the algorithm is not reliable any more? How does forest density affect its accuracy? What is the effect of wet snow present in the bottom layer as a result of geothermal heating? How can density values used as input to the algorithm be estimated with the required accuracy? A few answers to these questions are given in this paper, based on ERS-1 and RADARSAT data, but also on backscattering simulations with a multilayer SAR backscattering model for snow covered soil and informations coming from meteorological observations and hydrological simulations. For instance, the presence of relatively thin ice layers, should not affect very much the accuracy of the algorithm. However, refrozen layers with clustered ice grains reaching larger diameters may have a relatively large effect on backscattering. Even if trees affect backscattering, informations on the water equivalent of a snowpacks can still be obtained while the forest density is not too high.

A few algorithms have also been suggested by various workers in the past three years for wet snow mapping, each of them based on the lowering of backscattering coefficients with increasing water content in the snowpack. A difference of 3dB was considered sufficient to map wet snow. It was also shown that the addition of a second criteria allowing a specific pixel to be considered as containing wet snow only if its backscattering coefficient was below a pre-determined value, was improving the accuracy of the algorithm. It is also possible to map wet snow in forested areas up to a certain density. But, can wet snow mapping be done at any of the RADARSAT modes with acceptable accuracy? How does the increase in water content expressed in percent affect that accuracy? What can be done with complex snowpack made out of dry new snow, refrozen layers with large clusters of ice grains and wet snow at the bottom? This paper tries to give at least partial answers to these problems, based on SAR images or on simulations backed by good field data, past meteorological weather and hydrological simulation.

EQ-EAU : An Operational Monitoring Prototype for Snow-water Equivalent Estimation from Radarsat Images

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Preparation of hydrological forecasts based on estimation of snow-water equivalent on large watersheds dedicated to electricity production in northern Quebec is an essential operational task for Hydro-Québec. Indeed, a better assessment of the areal distribution of the water equivalent of the snowpack (SWE) leads to an improved stream flow forecasting accuracy. With the purpose of evaluating the implementation of SAR technology to obtain more accurate SWE, a joint project including INRS-Eau, Hydro-Quebec and VIASAT Géo-Technologies was started a few years ago. Encouraging results having been obtained with ERS-1 images, the next step was to verify the potential of RADARSAT imagery.

A follow-on project was then started, with the help of the ADRO (Application Development and Research Opportunity) program of the Canadian Space Agency, with the objective of adapting the ERS-1 algorithm to RADARSAT data and developing a prototype of an operational procedure allowing estimation of the water equivalent of the snow cover over the La Grande watershed, in northern Québec.

As various products are available with RADARSAT, one of the objective of the project is to select the most appropriate mode and acquisition strategy, given the accuracy of the radar data, the monitoring requirements and the dimensions of the watershed. The other one is the development of a software package allowing estimation of values of snow water equivalents meeting Hydro-Québec spatial integration requirements in a format compatible with their GIS software. This software package will include the following modules: estimation of snowpack water equivalent (SWE) on a pixel by pixel basis, spatial integration of SWE for specific grid sizes or watershed boundaries, production of statistics and interface with Mapinfo.

Calibrated RADARSAT images, in both Standard and Wide modes,have been acquired during the 1996-1997 winter and will also be acquired for the 1997-1998 winter, but the watershed being very large, ScanSAR images will also be acquired and evaluated. The first results indicate that images taken at small incidence angles, corresponding to ERS-1 angles, might give more accurate estimations due to a larger dynamic range than those acquired at larger incidence angles. Also, in our first tests, the new RADARSAT algorithm has been able to furnish estimations of the water equivalent of the snowpack within 1 % of the mean value of our 34 tests sites.

The paper will report on the accuracy of estimations reached with various RADARSAT products. Also, the various steps of the estimation procedure included in the operational prototype will be presented.

Classification of Snow Scattering Behaviour using Polarimetric Decomposition Theorems

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During two of the Space Shuttle missions in 1994, polarimetric data was collected by the Jet Propulsion Laboratory SIR-C sensor over the French Alps during April and October at both L and C bands. Monitoring snowpack characteristics in this environment being important, a project was started to study the polarimetric properties of the snowpack and to develop a new approach for snowcover mapping based on polarimetric scattering mechanisms.

The objective of this paper is to present a preliminary classification procedure based on the analysis of the various polarimetric scattering mechanisms from the snow and soil layers.
The use of such a classification is motivated by the following considerations:

1) Scattering from snow is generally studied by means of complex and numerically intensive models. These models have to take into account various types of scattering such as, rough or smooth surface scattering, volume diffusion, multi-layered medium, etc. A simple way to realize this classification consists in associating a type of snow to a peculiar scattering mechanism.

2) Multipolarization analysis is known to be more informative, and a large number of polarimetric discriminators have been successfully developed for snow mapping and classifying. Partially polarized wave problems may arise during the study of distributed targets. In the case of non-zero entropy problems, care must be observed using polarimetric behavior to classify targets.

The use of Polarimetric Decomposition Theorems based analysis meets both (1) and (2).
In our study, both Huynen and Cloude theorems are used. In the last case, non-pure targets can be decomposed into a sum of three orthogonal pure targets relating each to a scattering mechanism. The principal parameters of this decomposition are the entropy, which is the confidence ratio of the decomposition, the values of the targets, and their relative importance corresponding to their eigenvalues.

This procedure can be used as a first stage classifier, in a hierarchic structure, in order to transmit data to smaller and more restrictive models, but in a more efficient way.

The classification is applied to the SIR-C data, the resulting maps are validated by fine DEM and Landsat optical data. Field measurements were collected by Météo-France and EDF, and a snow metamorphism model from Météo-France is used for regional validation.

Characterization of Snow and Ice by Means of SIR-C/X-SAR and AIRSAR Data

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Signatures of snow and glacier covered areas have been analyzed from polarimetric SAR data at C-, L- and P-band and single polarization X-band data. The data set includes AIRSAR images from 25 June 1991 and SIR-C/X-SAR images from April and October 1994 (SRL-1 and SRL-2), acquired over the high alpine test site Oetztal in Austria. Ground measurements and meteorological observations are the basis for interpreting backscattering from ice-covered and ice-free surfaces. The snow and ice conditions on the glaciers were different at the time of the three experiments. During the AIRSAR overflights the snow cover on the accumulation areas was wet and only small ice areas were exposed. In April 1994 typical winter conditions were observed, with up to 3 m of dry snow covering the glaciers and the surrounding areas. In October 1994 the weather conditions changed during the experiment, at the beginning the air temperature exceeded 0°C decreasing to -12°C within 5 days.

When the glaciers are covered with dry snow all the backscattering coefficients are relatively high and the HHVV correlation coefficient is low. On the accumulation areas typical values at C-band and 50° incidence angle are -7 dB and -11 dB for co- and cross-polarization, respectively, the magnitude of the correlation coefficient is about 0.22. For wet snow with smooth surfaces (June 1991) the backscattering coefficients are lower, about -21 dB at VV and -32 dB at HV polarization for the same incidence angle. The magnitude of the correlation coefficient is about 0.6. In summer backscattering coefficients of bare ice are significantly higher than for wet snow because of the larger roughness. During SRL-2 an increase of the backscattering coefficients as a consequence of the gradual freezing of snow could be observed with X- and C-band data.

Total backscattering from a snow layer covering the ground has been modelled with IEM and Rayleigh scattering as a sum of surface and volume scattering terms. The model is applied for snow covered terrain in two cases, dry and wet snow. Although the snow structure in the model is strongly simplified, as it does not include internal layers and the grain size distribution, the calculations enable better understanding of the scattering mechanisms at the various frequencies. At X-band the volume scattering term is important at incidence angles above 45° for dry snow, whereas at lower frequencies the backscattering at the snow/ground interface is dominating. Large co-polarized backscattering coefficients at L-band were observed in October for slightly wet snow on glaciers, which can be explained by the contribution of scattering at internal ice layers and possibly also at the snow/firn interface.

The main backscattering parameters for discriminating snow, firn and ice are the X- and C-band backscattering coefficients and the magnitude of the HHVV correlation coefficient at C-band.

Seasonal Evolution of the 1988-89 Northern Great Plains Snow Pack from Satellite Passive Microwave Observations

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The Northern Great Plains are well suited for passive microwave studies of snow packs because the area contains little elevation relief and consists mostly of open prairie or farmland with some forested areas found east of the Red River. In mid-February 1989, the NOAA National Operational Hydrologic Remote Sensing Center carried out an extensive survey of snow water equivalent using airborne gamma ray attenuation techniques. This survey was performed in the Red River basin, within a 200 km by 250 km region, and consisted of 92 flight lines, that were nominally 10 km long. These observations provide a unique data set of snow water equivalent determinations on spatial scales similar to the satellite passive microwave observations as acquired by the DMSP SSM/I F-8 satellite. Analysis of these data set showed that the passive microwave response, at the time of the gamma ray survey, was similar to the response predicted by MIE scattering theory for a snow grain size of 0.7mm. During the rest of the snow season, we observe four periods of large changes in the SSMI snow pack signatures. National Weather Service (NWS) point measurements of snow depth and surface temperature from across the region are used to determine the causes of these changes that are seen in the SSMI signals. These effects include apparent changes in snow pack grain size that results from freeze/thaw conditions. These observations allow us to adjust the parameters in the algorithm to improve snow depth estimates. Therefore, accurate algorithms for determining snow pack water equivalent should use a time series approach rather than a snapshot at one time during the winter season.

Session K03
Tuesday, July 14, PM 13:40-18:00
Room J
Remote Sensing of Natural Media

Organiser : F. Yanovsky
Chairs : F. Yanovsky, A. Nosich

Clear Air Attenuation Maps for the United Kingdom at Millimetre Window Frequencies

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With so many present and future satellite communications applications operating at millimetre wavebands, it is particular relevant to evaluate the clear air attenuation component. Clear air attenuation can be evaluated either by the specific ITU recommendation or by more sophisticated semi-theoretical models such as Papatsoris's APM [1]. The ITU model is based on ground parameters and corrects attenuation for rainy conditions via the effective height concept.

Nevertheless, this model ignores the variation of atmospheric parameters along the entire depth of the atmosphere and consequently should be used only as a first approximation to attenuation estimation.

In this paper we utilize historical radiosonde data from several weather stations around the United Kingdom to determine accurately the clear air attenuation at 93 GHz. The input data, ie, atmospheric pressure, temperature and humidity as a function of altitude are fed to APM which in turn evaluates clear air attenuation. The data have been collated from the eight permanent UK Meteorological Office upper air stations. The radiosondes are currently released every six hours and report measurements which are continuously recorded. The database covers years 1990 to 1997 with approximatelly 7000 profiles for each station. The APM calculated mean zenith attenuation for each month is compared to ITU-R predictions as well as to 93 GHz radiometric measurements collated at York University.

From these results, monthly gaseous attenuation maps for the United Kingdom are proposed.

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A Treasure Trough of Data : Plans for the Utilization of the DOE-ARM Data-Stream for Cloud Studies

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The ongoing U.S. Department of Energy (DOE) Atmospheric RadiationMeasurement (ARM) program is producing a valuable data-set for remote sensed observations. Our group at PennState University has been working on a diverse set of techniques to invert these remotely sensed observations into cloud properties. These include velocity power spectra-, and combinations of lidar/radar-, microwave radiometer/radar- and solar/IR flux/radar-inversion techniques. In all cases we determine the radiatively important parameters in addition to other variables such as turbulence or droplet spectrum parameters. We place a high emphasis on the validation of our inversion techniques with in situ data.

Our objective is to use the ongoing ARM data-stream to calculate time-series of these important parameters for the development and testing of parameterizations cloud processes in the atmosphere. The ARM data-stream is available to any researcher, and includes a set instruments providing observations on a continuous basis, augmented by intensive observational periods where several additional instruments are added to the standard set, and in situ measurements for verification are provided by multiple aircraft.

We will discuss our various retrieval techniques, and point out how the ARM data-stream will be utilized.

The Influence of Atmosphere Turbulence on Spectrum Fluctuations of Intensity of Reflective Non-Monochromatic Signal

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In the works [1], [2] it was shown, that the internal structure of the meteoobject could be determined from the analysis of intensity distribution of reflective signal when the probe signals with different width of the spectrum Δk ($\Delta k = 2\pi / \lambda$) were used.

Our theoretical investigations show that the atmosphere turbulence essentially influences on character of reflective monochromatic and non-monochromatic signals. And the principal difference in intensity distribution of reflective signal for multiple meteo-target and system of small number of scatterers is observed.

It is shown , that the dynamics of variations of average distances between the scatterers can be defined if the system of small number of scatterers is exposed to influence of probe radiation signal with variable width of spectrum. Statistic analysis of such dynamics gives an opportunity to estimate the atmosphere turbulence parameters.

During the work the special computer program was created. This program allows to model the reflection process of radar signal with various widths of spectrum from arbitrary number of scatterers with arbitrary distance projections on radiation direction and to analyse fluctuations of intensity of reflective signal.

Measurements were made for probe signals with proportional and Gauss spectral distribution in interval Δk . Width of spectrum could periodically change in interval $0 < \Delta k < \Delta k_{max}$, $\Delta k_{max} > \pi/d$, d - the average distance between scatterers in direction of radiation.

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Optical Properties of Unspherical and Oscillating Raindrops

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Optical properties of a spherical water drop are well known. But the falling raindrops are not spherical and can oscillate as they fall. These result in the essential changing of their scattering phase-function.

The scattering phase function of unspherical and oscillating water drops were measured in the laboratory conditions. A water drop has been suspended on a thin loop oscillated in the vertical direction. When the frequency of the loop vibration coincided with the characteristic oscillation frequency of the drop, the resonant exitation of the corresponding drop harmonics occured. The oscillating drop was illuminated from below by light and a scattered radiation was measured. Within the scattering angle range from 100^{O} to 160^{O} , an abnomal high modulation of light, scattered by the oscillating drop was detected. The effect was so great that we registrated less than one micrometer oscillations of drops of 3 mm in diameter.

At the first approximation the form of falling raindrops may be considered as spheroidal. So, the scattering phase function of a spheroidal water drop was calculated theoretically at the straight line approximation. It was shown that the scattering function is very sensitive relative to a drop deformation. For example, the dependance of Θ_{rb} - angular position of the first order rainbow on the relative drop deformation $\Delta D/D$ for the refractive index $n = 1.328$ may be approximated by the equation $\Theta_{rb} = 137.2^{O} +267.6^{O}\,\Delta D/D$, where 137.2^{O} is the first order rainbow angle for a spherical drop. It was shown that the high modulation effect was caused by a very great sensitivity of the rainbow angular position to a drop deformation. The second order rainbow also has interesting properties; for example, at the some definite deformation it is devided on the three branches.

The abnomal high modulation effect was used for the remote measurements of raindrop oscillations under the field conditions. The sensitivity of this method was so great that it allowed to registrate the 3 micrometer deformations of falling drops from the 10 m distance. The statistical treatment of the field results has shown that the oscillation amplitude of falling raindrops of the same diameter were not the same in different rains and, perhaps, it depended on the rain intensity and (or) on the intensity of turbulence and wind pulses. This problem is not clear so far. But practically for all cases we have approximated that the average amplitude of drop oscillation increases with the increase of a drop diameter according the square law.

The fact that almost all raindrops oscillate as they fall allows us to suggest a scheme for the remote optical disdrometer, which measure the the drop diameter spectrum on the basis of the abnomal high modulation effect. As the oscillation frecuency depends on drop volume, and drops of different diameter form different parts of scattering light intensity spectrum, we can reconstruct a drop size distribution by means of the remote optical measurements.

Application of Doppler-Correlation Principle to Wind Measurements

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The Doppler-correlation principle of velocity measurement summarize advantages of a continuous wave Doppler systems and pulse systems: it has no restrictions on velocity and distance resolutions has no limitations on values of registrated velocity and distance, it can use any wavelength. The results of theoretical investigations, computer simulations and field condition measurements are considered and discussed.

The method is based on using of a radar, that can operate on two different modes: the first is a continuous wave mode, the second one is pulse incoherent regime. As a result two different functions are measured simultaneously along the trajectory: the first is a total Doppler spectrum S(V,t), where V - is a generalized Doppler frequency, which is equal to projection of velocity on beam direction, the second function is backscattered signal intensity I(R,t) as a function of distance R and time t. Usually a spatial distribution of scatterers is random, so the intensity of the received signal fluctuates with time t. The fluctuations simultaneously occur both in the Doppler spectrum and in the profile of intensity along the ray. Analysis of the temporal correlations between these two functions allows to reconstruct the profile of radial velocities of scatterers along the trajectory.

Doppler-correlation reconstruction of a velocity profile from the mathematical viewpoint is a solution of the inverse problem. The results of theoretical investigations of the direct and inverse problems are submitted in the report. Computer simulation of this principle have shown that it can reconstruct any wind profiles, it has no restrictions on registrated velocity and distance and on velocity and distance resolutions. Results of computer simulations are discussed.

Experimental testing of Doppler-correlation method under field conditions has been realised by means of a pulse Doppler radar. From one side the registrated data were processed by a traditional manner and a projection of wind velocity V on beam direction was measured as a function of distance R, that is V(R). This profile has been taken as a basis, or as a control profile. From the other side the same radar was used for simulation of Doppler-correlation measurements. An integral Doppler spectrum $S(V,t_i)$ has been simulated by summation of spectra from all distances along the beam. This allows us to simulate continuous wave measurements of Doppler spectrum. At the same time t_i a dependence of signal intencity $I(R, t_i)$ on distance R was measured. As a result two functions $S(V,t_i)$ and $I(R, t_i)$ were "measured" at different time moments t_i. On the basis of these two functions a temporal correlation function was calculated, and profile V(R) was reconstructed by Doppler-correlation method. The Doppler-correlation profiles were compared with control profilers, registrated by traditional pulse method. Average velocity discrepancy not exeed 0.8 m/s at all distances.

The perspectives of application of the Doppler-correlation method in acoustics and optics are discussed.

A Model of Atmospheric Turbulence which Takes into Account the Effect of Imperfect Response of Scatterers ontothe Turbulent Contribution to Doppler Spectrum

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The detection of turbulence by radar methods in clouds and precipitation supposes that particles (scatterers) are being good involved in turbulent movement. Therefore Doppler spectrum, which is caused by the movement of droplets, contains some information about the turbulence. But one of the problems is that particles are not be perfectly involved in the turbulent motion due to inertia.

This paper analyses a model of the back-scattering by turbulized clouds and precipitation when they are sounded by radar signal. Eddy dissipation rate is used as a fundamental parameter of the turbulence that characterizes the intensity of the turbulence. Because of it does not depend on a scale of the turbulence (we analyze the inertial subrange only), the eddy dissipation rate is convenient as an initial parameter for the simulation.

Our basic supposition is following. We assume that the minimum space scale of the turbulence L_{min} exists for the each group of drop size. The whirlwinds with spatial scale $l>L_{min}$ involve into the motion all particles of size $r<r_o$. And opposite, all turbulence scales smaller than L_{min} do not render essential influence on the motion of particle if the particle sizes $r\geq r_o$.

A density distribution of turbulent velocity, which effects on the motion of particles with defined diameter is derived analytically based on Kolmogorov spectrum of turbulence and normal distribution of initial turbulent velocity distribution. This model is investigated under the different conditions. The influence of eddy dissipation rate, diameter of particles, radar resolution, direction of observation are studied and will be discussed in the paper.

The developed model can be used for the simulation of radar backscattering of clouds and precipitation, for establishing some relationship between radar signal and eddy dissipation rate and for signal processing.

Investigations of the Influence of Various Meterogical Parameters on the Statistical Characteristics of the Radar Signal

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The opportunity to use the senior moments of a Doppler spectrum of radar echo for a determination of main meteorogical parameters is shown. Parameters of a spectrum are:

Fd - Average Doppler shift of frequency or the first central moment of a spectrum

σ_F - Width of a Doppler spectrum or square root from the second central moment of a spectrum

Sk - Assymmetry of a Doppler spectrum or relation of the third central moment of a spectrum to σ_F 3

Ex - Excess of a Doppler spectrum or relation of the fourth moment to width $\sigma_F{}^4$

We shall accept, that the distribution of a raindrop sizes is submitted Marshall-Palmer law.

$$n(d) = N * e^{-\alpha d}$$

Therefore, each of listed parameters of a spectrum depends on the three most important meteorogical parameters: intensity of a rain I , vertical gradient of speed of the wind dV/dh and the speed of the dissipation of the turbulent energy ε.

Thus a following system of equations takes place :

$$\begin{aligned} \sigma_F &= f_1 (I, dV/dh, \varepsilon) \\ Sk &= f_2 (I, dV/dh, \varepsilon) \\ Ex &= f_3 (I, dV/dh, \varepsilon) \end{aligned} \qquad (1)$$

This system permits to determine main meteorogical parameters I, dV/dh, ε, if σ_F, Sk, Ex are measured. In a number of cases a system (1) allows simplifications. For example, sizes σ_F, Sk and Ex don't depend on N(d), when a sounding angle is close to horizon. Accordingly system (1) comes to a system of two equations.

$$\begin{aligned} \sigma_F &= f_1 (dV/dh, \varepsilon) \\ Sk &= f_2 (dV/dh, \varepsilon) \\ Ex &= f_3 (dV/dh, \varepsilon) \end{aligned} \qquad (2)$$

The system (2) permits to determine dV/dh and ε in it's all real range of change with accuracy ~ 20 % at an error of measurement σ_F, Sk and Ex about 10 %.

When sounding angle close to a vertical, sizes σ_F, Sk and Ex do not depend on dV/dh practically. The system (1) can be simplified similarly and it will allow the decision in a real time scale.

The correlations of dispersion of estimations σ_F, Sk and Ex with presence a noise, are received.

Wave Pattern of Guided Radar System

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The theoretical and experimental investigations of the near field radiation pattern of guiding radar system based on the buried leaky coaxial cable (LCC) are presented for various artificial and natural local inhomogeneous conditions. The theoretical model of two coupling waveguides, external of which consists sub-soil medium, is introduce to describe interactions of two modes, external and internal which determine the working characteristics of such a guiding radar. It is shown, that the propagation characteristics of internal mode can be considered in standard manner. The propagation characteristics of external mode can be considered as for an insulated single wire cable buried at some depth in a inhomogeneous sub-soil medium. Analysis shows that the propagation constant is found near the wavenumber of the insulating layer, perturbed by losses in the sub-soil medium and by the presence of the interface. The main property of this mode is the very large value of the attenuation constant. The simple estimations show that the propagation constant does not vary greatly with the burial depth. The theoretical analysis shows, that the main parameters affecting the performance of such a guiding radar system are the *attenuation,* which limits the longitudinal range of LCC, and *coupling,* which determines the overall sensitivity and field pattern of radar system. At the same time, the coupling coefficients also depend on the internal and external parameters of LCC and sub-soil medium. *Attenuation* is relatively easy to measure by simple insertion loss techniques, although the accurate prediction of losses in an actual working environment is much more difficult. *Coupling* is the measure of the signal accessibility at a given radial distance outside the cable and, being very dependent on the particular installation and environmental aspects, is very difficult to assess.

In the experiments we used the loop of the LCC buried at the depth 10-15 cm. The length of the cable is equal to 144 m. The carrier frequency is ~40 MHz. The measurement of the characteristic impedance of the cable give 51 Ω at the frequency used. We studied the vertical and the horizontal distribution of radiation along the cable. The electric field intensity was measured each 1.5 m along the cable at the height ~0.8 m above the ground. Further, we studied the possible influence of screening objects located near the guiding radar system above the ground surface.

Analyzing the presented experimental data, we can conclude that the field pattern of buried guiding radar system along LCC has a regular structure at the ranges more than 20-30 m from the generator. Near the generator the strong fading of external mode signal is observed. This fact can decrease the performance of such guiding radar system. Moreover, the radiation pattern essentially depends on the sub-soil conditions. The wet soil decreases antenna pattern at the 25-30% in comparison with that of dry soil.

Modeling Reflector Antennas in the Presence of Earth

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Potentials of the remote sensing of atmospheric and other natural phenomenain various media are essentially limited by the antenna performance. Shape and stability of the mail beam and the sidelobe level are greatly effected by the presence of local objects and earth surface. The featutes of this effect can vary due to a change of the earth properties.

The paper presents basic ideas, equations and analysis results of a novel approach to numerical modeling of reflector antennas in the presence of flat earth. Our goal is obtaining a tool to compute the currents and far-field patterns with a guaranteed accuracy in the wide range from quasi-statics to quasi-optics. The fundamental idea that underlines this approach is analytical regularization. That is why the term 'Method of Regularization' (MoR) is used, implying the conversion of the electric-field integral equation (IE) to an integral, and eventually infinite-matrix, second-kind Fredholm equation. A secondary but important idea is using the complex source-point (CSP) field as a primary feed, in order to simulate a directive radiation but avoid any inaccuracies due to approximating the right hand part of IE by a function that is not a solution to the wave equation [1], [2].

The dual-series-based MoR technique was first developed for the scattering from thin regular PEC screens such as circularly curved strips and spherical caps; resistive and impedance-surface ones are also treatable. MoR can be considered as a sophisticated version of the Galerkin MoM due to a very judicious choice of expansion functions: they must form a set of orthogonal eigenfunctions of the static part of the corresponding original IE. Then the matrix equation to be solved is a Fredholm second-kind one, hense the existence of exact solution and the point-wise convergence of the discretization scheme are guaranteed.

This was first illustrated by the free-space reflector analyses [1]. All the main features of reflector antennas are easily computed and clearly observed. Overall characteristics such as total radiated power, directivity and gain can be found accurately that opens a way for an optimization of antenna. Numerical efficiency of MoR, in terms of CPU time, is estimated as hundreds of times higher than with conventional MoM based on sub-domain or entire-domain basis functions. Generally, the advantages of the MoR approach are more clearly evident for the reflectors not in free space but in complicated near-field environments. Several problems of this sort has been solved with the above combination of MoR and CSP [2]. Reviewed here is a cylindrical reflector over an imperfect plane earth. Computed results show that the earth features, such as wet/dry condition, may change the directivity and gain of antenna up to 10\% of the peak value depending on the inclination.

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Electromagnetic and Scalar Waves Diffraction by Axially Symmetrical System of Circular Strip (Thin Rings)

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Antenna with controllable polarization is developed for the remote sensing of clouds and precipitation [1]. The novel technique of antenna diagram symmetrization at the switching of polarization uses the system of axially symmetrical rings [2]. That is rather difficult for analysis. A new mathematically rigorous and numerically efficient method for solving a boundary value problem of electromagnetic and scalar wave diffraction by axially symmetrical system of infinitely thin circular rings is proposed. The method is based on the combination of the orthogonal polynomials approach [3] and the idea of analytical regularization [2]. As a result of the suggested regularization procedure, the original boundary value problems equivalently reduced to the infinite system of the linear algebraic equations of the second kind, i.e. to the equation of the type (I+H)x=b in the space l_2 of square summable sequences. This equation can be solved numerically by means of truncation method with any required accuracy.

In the simplest case of axially symmetrical excitation of one cylindrical ring, the diffraction problem under consideration can be reduced to the equation of the form:

$$D\int_{-1}^{1} \ln|u-v|\, z(v)dv + \int_{-1}^{1} K(u,v)z(v)dv = f(u) + C_1\psi_1(u) + C_2\psi_2(u),\quad u\in[-1,1] \tag{1}$$

with unknown function $z(v)$, where second integral term has more smooth kernel $K(u,v)$ in comparison with first one (i.e. $D\ln|u-v|$); $f(u)$ and $\psi_j(u)$, $j=1,2$ are known functions. Accordingly to the type of excitation wave and whether the scalar or electromagnetic problem is under consideration, there are two possibilities: $D=1$ or $D=d^2/du^2$ - differential operator. Here C_1 and C_2 are unknown "free" constants, that have to be determined from the Meixner edge condition for field correct behavior in a vicinity of the thin edges.

For the axially symmetrical system of a finite number of the cylindrical screen with arbitrary excitation, the corresponding problem can be equivalently reduced to the system of type (1) equations. The first step of our method is based on the representation of unknown functions and kernels as infinite series involving the Chebyshev's polynomials and on analytical construction of the inverse operator to the first (differential-) integral operator in the left hand side of (1). The second step is construction of the two-sided regularizator of thus obtained functional equation. As a result, initial problem is equivalently reduced to the equation of the second kind in l_2 of the form $(I+H)x=b,\ \ x,b\in l_2$, where I and H are correspondingly identical and compact operators. Numerical experiments have shown that the method is efficient, numerically stable and reliable for considering class of diffraction problems.

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Meteorological Applications of Dual-Polarization Radars

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The review of theoretical and experimental studies of meteorological events by dual-polarization radars are presented.

Theoretical models of polarization characteristics (linear and elliptical) of radar signals from different kinds of clouds and precipitation are worked out and described. These algorithms were realized on the basis of air-borne and ground-based dual-polarization weather radars. These diversity-polarization radars are also discribed.

Experiments have been carried out for studying the evolution of the microstructure of clouds and precipitation during their natural development and weather modifications. The results of these studies have shown that polarimetric characteristics of radar signals make it possible to distinguish the microstructure and development stages of cumulonimbus.

In particular, using polarimetric information, a hailfall region can be determined and zone of large supercooled part of the cloud is connected with the updraft regions and serves as additional information for determining the seeding region in hail suppression and intended precipitation enchacement operation. Use of the correlation values allow neutralization of the signals from interfering objects and polarization selection of clouds and precipitation of different structure and its discrimination from ground clutter.

The typical polarization characteristics of the vertical and horizontal sections, the evolution of clouds during their natural development and weather modification, are presented.

The Adaptive Threshold Data Processing for Buried Object Detection Problem

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The report deals with the data processing of the underground radar signals scattered by the buried objects. The algorithm discussed is the adaptive threshold algorithm (ATA).The ATA has advantages in comparison with the invariable threshold processing. It doesn't require a preliminary compensation of the attenuation in the media, essentially decreases the number of the background readings and gives an appropriate contrast of the reflected signals. These advantages are most prominent for the detection of weak scattering objects and in other difficult situations, where conventional processing with the zero threshold results in very complicated images.

The results of the numerical simulation are given for the different types of transmitted signals including ideal pulse signals and signals with «ringing» due to the limited frequency band of the antenna and multiple reflections.

The efficiency of the ATA depends on proper choice of the training sample. The training sample can be determined by a two-step procedure. At the first stage, the training sample contains all scattered signals in the processed sector. From an analysis of results obtained at the first stage, an operator specifies the coordinates of the area to be checked and adjusts the boundaries of the processed sector. The next stage consists in automatic choice of the training sample according to the criterion of the minimum intensity within the checked range of delays under the condition that its minimum volume is given.

This two-stage procedure reduces to an automatic one-stage procedure if the adaptive processing is applied separately to each given delay.

The ATA was used for experimental data processing and provided an improvement in the detection of underground objects.

Session L03
Tuesday, July 14, PM 13:40-14:40
Room R01
Biological Effects II

Chairs : J. C. Bolomey

A Hybrid Method of Moments / Method of Auxiliary Sources (MoM/MAS) Techniques Applied to the Calculation of the Electromagnetic Field Generated by a Hand-Held Transceiver in Various Head Models

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In recent years there has been a growing demand for accurate dosimetric calculations inside lossy bodies exposed to the near field of hand-held transceivers. The absorbed power in the human head is considered to be the most crucial parameter in assessing the potential hazard caused by the use of mobile communication devices. As several calculation methods have been developed by many researchers, an effort on an international level is being made in order to ensure both the validity and the applicability of the methods, in terms of computing time and memory demands. Therefore, basic canonical problems have been proposed for comparing different numerical treatments.

The aim of this contribution is to present a recently developed hybrid technique, based on the Method of Moments in conjunction with the Method of Auxiliary Sources (MoM/MAS), as applied to the calculation of the electromagnetic field distribution inside the human head irradiated by a dipole antenna. The MoM/MAS technique has proven to be particularly efficient especially in cases where coupling between conducting surfaces and dielectric bodies takes place. The well known advantages of MoM are combined with the significantly low computational cost of MAS when applied to arbitrarily curved conducting surfaces.

The contribution of the head model is taken into account by using 'traditional' MoM. The head model is subdivided into elementary cubic cells, each one of them is characterized by a generally different complex dielectric permittivity. The electric field inside each cell is described by an adequate combination of roof-top functions. This ensures satisfaction of the pertaining boundary conditions. The contribution of the surface of the dipole antenna is taken into account by considering auxiliary sources distributed on a virtual surface which lies inside the physical surface of the antenna. The emerging system of coupled equations is solved using a bi-conjugate gradient method.

Numerical results referring to layered spherical and cubic canonical models as well as to anatomy based models of the head are presented and compared with predictions of other techniques (e.g. exact Mie theory for the spherical cases, Finite Difference Time Domain technique (FDTD) etc.). The calculated quantities include the Specific Absorption Rate (SAR), the total absorbed power within the phantom with reference to the total power radiated from the source, the input impedance at the feedpoint and the radiation pattern. Comparisons of computing times and memory demands are also presented.

In conclusion, MoM/MAS seems to be an efficient technique for predicting the deposition of electromagnetic energy in the human head when irradiated by hand-held transceivers.

Cellular Phones, User Intercations : Effect of Clothes, Metallic Glasses and Jewels on the Far Field Pattern

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I) Introduction

A better of the radiated field by cellular phones in presence of the user can provide an useful assistance for improving cellular links power budget predictions. Characterizing the equivalent antenna made of the user and his handset require the evaluation of the effects of parameters which can influence that far field.
This work presents an expiremental assessment of the influence of clothes and metallic objects close to the handset (like spectacles and jewels) on the far field radiated by the aboved mentionned equivalent antenna.

II) Measurement tools

A validated phantoms, made of empty polyurethane sheathing filled with a muscle equivalent liquid have been used to replace volonteers for repeabilities purposes. Equired with a cellular phone, the phantom is installed on a turntable with vertical axis and rotate for each position of a translated probe following a vertical line. The probe measures the two tangential components of the electrical near-field (NF). At the end of the measurements process, the NF distribution is known on an open cylinder surrounding the equivalent antenna under test. Via NF transformations based on modal expansion of the field, the amplitude, phase and polarisation of the radiated far-field in almost directions are calculated.

III) Results

At GSM and DCS frequencies the size of spectacles's arms are about one to half the wavelength. We compare the far field radiated by a NEC2 simulated handset in absence or presence of metallic glasses and without the user. Computations show strong differences between both cases. Experimental NF tests conducted on the phantoms wearing or not the glasses show no noticeable differences between both configurations. Others NF measurements conducted with metallic earrings an necklace in standard position on the phantom provide the same result. The high permittivity of the user tissues explains this : the inducted current on the metallic structure radiate essentially inside the user and very few outside. Measurements with clothes consist first in evaluationg the modification of the reflection and the transmission between two antennas when placing clothes between them. Small modifications occure even for thick clothes : a leather jacket for an example. Measurements performed with phantom wearing or not the clothes show no noticeable differences on the radiated far-field. The permittivity and the thickness of the clothes are not sufficient to induce significant effects.

IV) Conclusion

These results suggest that objects weared by the user does not influence significantly the far field pattern of the cellular phone in presence of its user. The perspectives are to find statistical models for the phone/user equivalent antenna and to test several kind af antenna for the phone.

Acknowledgment : This work was supported by CNET/France Telecom under grant n°941B087.

The Parameters of the Bioinformational Channel on Longitudinal Electromagnetic Waves

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In the Scientific-Research Institute of Modern Medical Technolo-gies two laboratories (i. e., Lab. of Biophysics of Fields and Radiations and Lab. of Bioinformatics and Modeling of Life Activity Proces-ses) study physics, dynamics, propagation processes and role of the longitudinal waves (LEMWs) in bioinformational exchange in Biosphere and Noosphere. It's necessary to note that the Tula school of bioinformatics is the world leader in the mentioned field of studies. (The scientific managers are ac. Nefyodov E. I. and ac. Yashin A. A., who have published many scientific works on the subject in different issues.)

The physicists and scientists working in the field of microwave and EHF electrodynamics have taken interest in LEMWs in the late 80-ies and the early 90-ies. The interest was connected with the names of such Russian scientists as N. P. Khvorostenko, Yu. N. Kuznetsov, ect. Firstly physicists have studied only the physical phenomena of LEMWs and theoretical algorithmical constructions. But the hypothesis that LEMWs play a specific role in the processes of local and global (noospheric) bioenergoinformational exchange has stimulated practical research into physics of LEMWs and their interactions with bio-objects. Complex work is currently under way on the study of parameters of the perceptive channel of bioinformation on LEMWs.

The Maxwell's equations assume the existence of longitudinal electromagnetic waves alone with transverse ones used widly. It does not contradict the physics laws. LEMWs can serve as a physical (material) carrier of the perceptive channel of information including bioinformation. When analyzing the parameters of such a channel on LEMWs, the role of longitudinal waves in the structure of the common informational field of the Noosphere is a matter of particular interest. The mentioned articles analyze the meaning of the informational field of the Noosphere of the Earth on the base of the premise that initial elements in the scale of ranks of material formations are substance and field. From this point of view the Noosphere's informational field (IF) is a very complex material substance that is defined by globality, multi-dimensionality, communicativeness; possesses a variety of material carriers with the prevalence of electromagnetic field and dynamism of their transformations ; and develops keeping step with evolutionary processes accompanying reasonable activity of the mankind.

The peculiar feature of LEMWs is their high penetrability and high velocity of propagation, that is characteristic of the appropriate channels of information.

To evaluate numerically the main characteristics, one needs developed, consistent and adequate theory of LEMWs. The latter is under development, with its original conceptual basis (i. e., physics and electrodynamics of transverse electromagnetic waves) widening.
It means that in addition to substance and field there is a further point to be analyzed, and namely : the model of physical vacuum (PV) as an additional "reference point" for studying basically new effects of the PV that allows to evaluate the main parameters of the perceptive channel of bioinformation on LEMWs, because it satisfied requirements for consistency with universal properties of the substance and is constructed by means of concretization of laws content and basic categories of materialistic dialectics in conformity with the PV description.

Based on PV representations we have calculated the parameters of free-electron oscillation and then obtained values of substance parameters (taking water and limestone as an example). These values were in full accordance with values obtained experimentally. It was concluded that the quantum of longitudinal-wave energy is by 5 orders of magnitude greater than the quantum of transverse-wave energy. This fact allows to state that LEMWs play the specific role in the global bioinformational exchange so long as carrier of such an information is bound to effect at a super-great distance by some few quanta and with high penetrating power. The latter feature makes LEMWs "invisible", i.e., it is difficult to detect them with general-purpose physical devices because of: 1) a small mean-effective value of these highly-energy quanta; and 2) the obscurity of polarization characteristics of LEMWs.
Presently, bio-objects are the most effective detectors of LEMWs. This detection is indicated through changes taking place in properties of the bio-objects which are tolerant of other types of radiation. For example, LEMWs effect has been experimentally substantiated with Drosophila melanogaster mutation, whereas transverse electromagnetic waves did not induce any mutations. (The experiments have been performed with LEMWs generators designed by authors' developments.)

LEMW parameters have been estimated by means of analysis of the atom model generalising Bohr's model and quantum-mechanical concepts. The model has account of electron oscillation with reference to a nucleus, with the maximum of oscillation velocity being numerically equal to propagation velocity of LEMWs. But frequancy of resonant transition of energy from a transverse mode to a longitudinal one is a peculiar feature of the working substance of the perceptive channel and ranges 0.1-1 THz.

Calculated frequancy of the quantum of longitudinal radiation is equal to:

$$f_3 = \frac{m_{ээ} c^2}{2h_3} = 0{,}5 f_3 \frac{c^2}{V_3^2}, \quad \text{or } f_3 \approx 1{,}8.10^{11}\ \text{Гц},$$

where $m_{ээ}$ - mass of free oscillating electron ; c - speed of light; h_3 - quantum of longitudinal radiation effect; V_3 - velocity of LEMW propagation.

The existance of longitudinal electromagnetic waves is consistent with physics laws and their real occurrence has been experimentally substantiated with mutagenic effect on Drosophila melanogaster. The quantum of longitudinal-wave energy is by 5 orders of magnitude greater than the quantum of energy of transverse electromagnetic radiation, that explains the high penetrating power of LEMWs. f_43_0 Value for a free electron belongs to the IR spectrum, and this is the specific band of distant interactions in the animate nature. Thus, there are good reasons to believe that LEMWs play a significant part in the global bioenergoinformational exchange.

Session L04
Tuesday, July 14, PM 14:40-17:20
Room R01
Wireless Sensor and Communications Techniques I

Organisers : A. Springer, R. Weigel
Chair : R. Weigel

The Near Range Radar Network (NRN) as an Example for a Multi-Sensor-System with Autonomous Communication Links

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At the DLR Institute for RF-Technology a network, consisting of several radar sensors for the purpose of surveillance and localisation of rolling aircraft on airport surfaces, is under development now. These radar sensors are equipped with low power (≈ 10 W peak) transmitters using a biphase pulse compression technique. In contrast to the ubiquitous radar, staring antennas with relative broad azimuthal beamwidths (60° - 120°) will be installed. The network is organized in cells of four transceivers each. One cell may have a typical lateral dimension of about one square kilometre. The four transmitter beams illuminate this common cell area, which may have any arbitrary oblique rectangular shape. Because of the wide antenna beamwidth the localisation can only be done by distance measurements in combination with a rapid multilateration calculation, so that in effect the system can deliver all target locations in a one second cycle to a computerised planning system, which supports the airport traffic controllers.

For the calculation process of all target locations, such a sensor network needs an autonomously running exchange of measured distance data between the transceivers. This is being done within each network cell by transmitting the measurement results, i. e. the radar reflection profiles, from three so called slave-radar-stations to a master-station by wireless communication links via the radar antennas and amplifiers. Therefore, all necessary data are concentrated at the processor in the master station, which is responsible for the determination of the object locations. Localisation measurements with all four pairs of radar stations in a cell are performed.

Furthermore, object velocity vectors are being determined by a range profile correlation technique which results in a better track smoothing and a more precise collision prediction.

An overview concerning the equipment design and hardware realisation as well as test results will be presented. An outlook with respect to further developmental efforts regarding the additional bistatic localisation technique between the four stations of a cell will be given.

Millimeter-Wave Communication and Sensor Systems : Transceiver Design and Technological Requirements

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In the recent years there have been rapid changes in the area of RF technology and systems. Many of our most important RF systems did not even exist about 10 years ago. Today we cannot imagine life without achievements like cellular telephone, digital satellite TV, fiber optic, or GPS systems, which are only possible due to enormous progress in the development of semiconductor technology, novel devices, monolithic integration, innovative assembly and packaging techniques.

Nowadays systems are emerging at even higher frequencies, since the necessary technologies are becoming mature and available. Millimeterwave (mmW) systems are of increasing interest, with respect to their specific advantages on the one hand, due to the lack of frequencies on the other. Besides the unique propagation property at low optical visibility, millimeterwave systems take advantage of the highly directive nature of antenna beams leading to good angular resolution even with moderately small apertures.

Today there is a growing market for medium to high volume commercial applications in the mmW frequency range above 24 GHz, like satellite communication, wireless TV, radio links and relays, industrial sensors, or automotive radar systems.

There are three different market segments for mmW communication: Wireless infrastructure serves point-to-point transmission links at 23, 26, 38, and 58 GHz, LMDS (local mulitpoint distribution systems) and MVDS (microwave video distribution systems) are used for point-to-multipoint services at 28 and 42 GHz, and there are new concepts of broadband satellite systems for multi-media employment having the need of 20 GHz to 30 GHz direct communication terminals.

The two most important application areas for mmW radar are industrial process control and automotive sensor systems. There is an emerging market for level gauging using radar based sensors. An example is the APEX radar level gauge from Rosemount working in the 24-26 GHz range developed in cooperation with Daimler-Benz Aerospace. Vehicular radar sensors have been developed world-wide by numerous companies and are investigated by all major car manufacturers: radar sensors for ground speed, acceleration, or drift measurements, for road condition recognition, pre-crash detection, parking aid, or back-up warning. There exist narrow-beam sensors for intelligent cruise control (ICC), collision or obstacle warning, radars with broader beams are used for stop&go operation, as lane change aid, or for side impact warning. Together with powerful signal processing algorithms high resolution radar systems allow roadside detection and lane prediction, thus making intelligent interpretation of traffic scenes possible. Market introduction of ICC systems is expected to take place within the next two years. At Daimler-Benz there is a long history in the development of automotive radar sensors. Different systems have been realized applying either the FMCW or the pulsed radar principle, using hybrid, partly, or fully monolithic microstrip techniques. Based on a GaAs MMIC chip set developed at Daimler-Benz an imaging radar demonstrator has been assembled and tested.

This paper will give an overview on commercial mmW radio and sensor systems. Based on the system requirements the specifications for the transmitter and the receiver will be derived, available technologies and MMIC key components including their performance will be discussed. Cost issues will be addressed and competing technologies will be compared. Results obtained from transmitter and receiver modules for different mmW communication and sensor systems will be given and discussed at the conference.

Planar Leaky-Wave Antennas for Mobile Communication Systems

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Due to the increase of data transmission rates the millimeterwave region around 60 GHz becomes more and more attractive for mobile communication systems. Herein the great bandwidth necessary for realizing the high data transfer rates up to 160 Mb/s can easily be realized.
Besides the mobile broadband systems (MBS) further applications like VIC (vehicle inter communication), COMIS (communication using millimeter-wave systems) and WCPN/ WLAN systems (high speed wireless customer premises local area network) seek for special antenna solutions. Due to the high atmospheric attenuation at 60 GHz frequency re-use is also possible.

Generally two demands have to be satisfied. First the antennas for transmitting and receiving purposes should have a crosspolarisation level less than 20 B, because bit error rates decrease significantly with low crosspolarisation level. Second two antennas will be used in a communication system. One antenna with a nearly omnidirectional radiation pattern as a transmitting antenna for equal illumination of an indoor environment and a second antenna with a directive pattern (~ 20 dB) as a receiving unit.

These requirements can in principle be realized by planar leaky-wave antennas. These millimeterwave-antennas are obtained by choosing properly dimensioned planar substrate-superstrate configurations. One special type of a planar leaky-wave antenna consists of multiple dielectric layers above a ground plane. To make the antenna as flat as possible a waveguide in the transverse plane of the antenna will be used as a feeding structure. Via a slot in the broadwall of the waveguide the energy is coupled into the dielectric structure. To achive the best input impedance matching a sliding short can be used as a tuning circuit, if necessary. The thicknesses of both layers define the scan-angle of the antenna. This implies the possibility of beam-steering.

For the transmitting antenna a scan-angle of 45° will be chosen to illuminate the room. The overall height of the antenna is less than 10 mm including waveguide mount. The area necessary to produce a gain of 10 dB is 100 mm in diameter. As dielectric materials air for the lower layer and a RT-Duroid with $\varepsilon_r = 3.38$ as upper layer are used.
The receiving antenna with about 20 dB gain is also designed having a scan-angle of 45°. But this antenna will have a radiation pattern only in one direction. This effect can easily be realized by introducing a corner-reflector close to the exciting slot. Again the overall height of the antenna is less than 10 mm. The size of the antenna is 70x50x8 mm^3 (length x width x height). This antenna can also be effectively used for illuminating corridors for e.g. monitoring purposes.
Both antennas do have a crosspolarisation level less than 20 dB.

Due to their easy design rules and low tolerance sensitivity (1% for the thicknesses) this leaky-wave antennas are suitable for low-cost communication systems or radar-systems.

New Saw-Covolver Techniques for Demodulation in High-Speed Spread-Spectrum Communications

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New structures of high-performance SAW (Surface Acoustic Wave) convolvers which use main and auxiliary SAW delay lines as well as external mixers etc., for the spread-spectrum (SS) communications have been invented 1. They have the function of self-temperature-compensations with no relation to TCDs of the piezoelectric substrates. Therefore, high-conversion efficiencies can be achieved due to the usage of strong-piezoelectric substrates. Recent direct-sequence (DS) SS communications, such as radio LANs, wideband-CDMA cellulars etc., use the modulations based on QPSK. Conventional demodulation procedures for QPSK signals, such as a coherent detection, use the carrier/clock-recovery circuits constructed with similar ones to Costas loops.

We have proposed new demodulation procedures for QPSK-SS signals using the new SAW convolvers, which provide detected I/Q-baseband data directly from the received RF or IF signals by taking correlation with a peculiar spread code given to the radio terminal. New convolvers can be also used for both the initial capture of synchronization and the detection of data, which are very important features not only to the common SS communications but also to the high-speed packet-SS data transmissions which require the very fast capture for initial synchronization.

Mutually independent two codes are assigned to i- and q-channel spread codes, respectively in QPSK-SS communications. We used the new convolver which was constructed with three SAW delay lines. The first one is used for the SS signals. The second and the third ones which are used for the local signals have the mutual propagation-path difference with the quarter-SAW wavelength. They provide in-phase and quadrature-phase components of the SS signals after mixing with the local signals using external mixers. Data can be detected by the weighting and summing procedures for each phase components according to two independent i- and q-channel spread codes. These demodulation methods can be applied to high-speed SS communications up to several-Mbps transmissions. Examples of the demodulation for 2-Mbps SS communications, i.e. each 1Mbps to each channel, are presented as the experimental results.

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Implementation of Binary Orthogonal Keying Schemes Using SAW Chirp Filters for Robust Wireless LAN Applications

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Mobile data transmission in industrial and indoor environment represents a challenging area in communications engineering. The multipath fading characteristic of the mobile radio channel as well as electromagnetic emissions from other devices result in severe signal distortions and thus often lead to limited accessibility of the mobile users. A wideband spread spectrum system with a bandwidth greater than the coherence bandwidth of the radio channel is able to overcome this difficulties. Wideband chirp signals are especially well suited to solve these problems because of their high correlation gain. The proposed system uses surface acoustic wave (SAW) devices for the generation and detection of the chirp signals. In the receiver a short IF-pulse at the center frequency of the filter (348.8 MHz) stimulates a chirp filter which generates a 2 µs long output chirp signal with linearly varying frequency from 308.8 to 388.8 MHz. Depending on the filter characteristic the frequency increases (up-chirp) or decreases (down-chirp). In the binary orthogonal keying (BOK) scheme an up-chirp represents the symbol '1' and a down-chirp the symbol '0'. The IF-signal is mixed up to 2.45 GHz, amplified and transmitted. At the receiver after downconverting the signal is fed into a matched filter which is an up-chirp filter for a down-chirp signal and vice versa. Thus the same filter design can be used in both the receiver and transmitter. An envelope detector follows the matched filter. By using SAW filters for generation and detection of the chirp signals their advantages like small size, low cost and high analog computation power compared to today's signal processors results in a robust low-cost communication system for indoor and industrial environments.

To increase the data rate from 500 kBit/s corresponding to the 2µs long chirp signal overlapping chirps have been used. A new chirp is stimulated every 500 ns resulting in a data rate of 2 MBit/s. Due to the quasi-orthogonality of up- and down-chirp they can be added to further double the data rate if on-off keying modulation is used. Simulation results reveal that the major limiting factors for the data rate are the intersymbol interference resulting from the overlapping of consecutive chirp signals as well as the non-zero cross correlation between up- and down-chirp. The chirp system has shown to effectively deal with the signal distortions resulting from the multipath environment even with simple receiver structures like envelope detection. An overview over the simulation results will be given and the results are compared with measurements made with a hardware demonstrator. Further enhancements of the proposed system will be discussed.

New Possibilities of Saw Devices for Passive Remote Sensing and Identification

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Surface acoustic wave (SAW) devices permit a passive remote sensing generally. For the use in wireless sensor interrogation systems the measurement of physical quantities on various places without power supply is possible.

Sensors with surface acoustic wave resonators (SAWRs) have been proved to be excellent high Q sensing elements. The advantages of SAWRs are high sensitivity, accuracy, long-term stability and the possibility of storing electromagnetic energy. When a SAWR is interrogated by a RF sine burst the stored energy will cause an attenuated oscillation after switching off the exciting signal. This SAWR response can be used for sensor applications.

The differential measurement is a well known method in SAW sensing to suppress unwanted dependencies of the radio channel and to increase the sensor sensitivity. Usually these applications employ a Two-Delay-Line- or Two-Resonator-Circuitry where the difference of two frequencies ideally depends only on the variable to be measured.

A sensor device with two SAWRs in different propagation directions has been developed. These propagation directions are depending on the quantity to be measured (e. g. temperature, pressure, etc.). As an example this paper shows a passive wireless combined temperature and pressure sensor application on quartz substrates.

In systems with multiple sensors the combination of the quantity determination and the identification of the sensor at the same time should be realized. The SAW technique allows to solve both problems simultaneously.

Identification devices ("ID-tags") in remote sensor systems requires the use of released frequency ranges. The European limitations in the ISM-band (433.92 ± 0.87 MHz) are too strict to be covered by conventional SAW-ID-tags based on reflection structures or tapped delay lines. Both types of devices suffer from the broad bandwith of the short impulse that are used to excite acoustic waves on them. To solve this problem, we propose a special SAW device design, derived from conventional tapped delay lines and optimized for wireless interrogation systems as a two-terminal ID-tag.

This new design allows low-bandwidth and low-power interrogation using long, unmodulated sine bursts. The device responds with a PSK-code sequence suitable for a new wireless CDMA-based identification system that allows a simultaneous interrogation of multiple ID-tags by using orthogonal codes.

Techniques for Interrogation of Passive SAW Sensors

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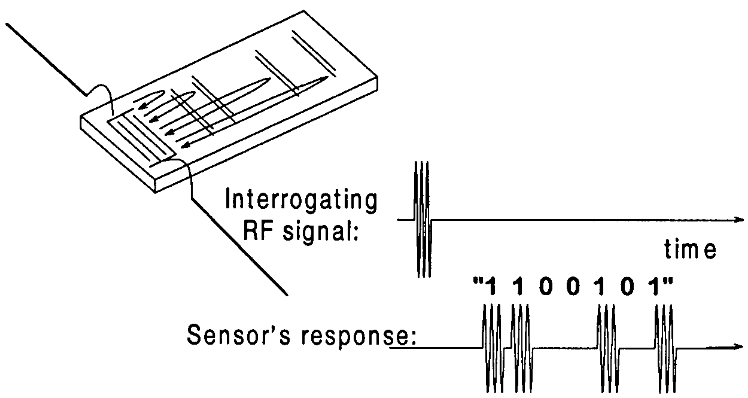
Since a few years, passive wirelessly interrogable surface acoustic wave sensors (SAWS) are applied in a rapidly increasing manner. For implementation, a one port SAW device is fixed to the location where the measurement have to be performed and is connected to an antenna. Therefore these sensors are totally passive devices, they consist of a piezoelectric substrate with metallic structures on its surface only and they contain no batteries nor semiconductors.

Since they are capable to withstand high thermal, mechanical and electromagnetic load, SAWS can be applied, where remote readout is necessary and other types of wireless sensor systems cannot be used in the surrounding environment.

Starting in the early nineties, the SAWS technology got an increasing importance up to now. The first industrial applications of the wireless SAWS were systems for identification purposes, e.g. road pricing. The sensor responds to an RF burst by a burst train, interpreted as serial data :



Affecting the propagation of the SAW on the substrates surface by an external influence, the sensor's response contain the quantity to measure. Nowadays, a lot of physical parameters can be measured by wirelessly interrogable SAWS.

For wireless readout some interrogation techniques have been developed. Operating different types of SAWS devices with different RF signals, yields an optimized performance of the systems with respect to interrogation range, duration of measurement, resolution, reliability and simplicity of the overall system.

In the presentation, the implementation of wireless SAW sensors for various applications is introduced. Then, the types of sensor elements and the according signals for interrogation are discussed, a comparison is given. The results are summarized.

Session M03
Tuesday, July 14, PM 13:40-16:20
Room R03
Near Field 2 : Near-Field Optics
Workshop on Complex Media and Measurement Techniques

Organisers : H. Cory, J. J. Greffet
Chairs : J.J. Greffet, U.C. Fisher

Optical Transmission Lines- Comparison Between the Optical and the Microwave Frequency Ranges

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We analyse the concept of the optical transmission line, a structure which can support propagation of a TEM mode at optical frequencies. Comparison between the optical and the microwave frequency ranges will be drawn and the differences will be analysed. The special emphasis will be placed on the application of these concepts to the case of the near-field optical probe. In near-field optics, the probe is a waveguide operating below the cut-off frequency. This results in a very low efficiency of the probes whereby on the output of the probe one typically gets 10^{-6} fraction of the power coupled to its input. We will analyse the prospects of applying the concept of transmission line to design an efficient optical probe. We will report on our experimental results on a single optical transmission line of a submicron size. We demonstrated enhanced coupling of light from a near-field optical fibre into the transmission line when a TEM mode was launched in the line. Application of the concept of the impedance matching is discussed for the case of the optical frequencies.

Near Field Optical Imaging of Light Propagation in Waveguide Devices

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The development of optical communications requires photonic devices with continuously decreasing size and increased integration, and progresses in analysis techniques should match this fast trend. While the far-field methods used so far have no longer the spatial resolution required, near-field scanning optical microscopy (NSOM) with sub-wavelength tips brought at sub-wavelength distances from the device surface is not limited by diffraction. It can in principle map with a very high spatial resolution the propagation of light (evanescent field) and the losses (scattered and absorbed fields) in guiding devices.

We show on various examples that NSOM can indeed yield a complete assessment of optical devices with sub-λ resolution: determination of the optical path, variation of the light intensity along this path, and measurement of local radiative losses. This information can be obtained on a variety of devices, channel waveguides and much more complex devices, based on III-V semiconductor, polymer, or glass materials, in the visible range as well as at telecom wavelengths (1.3 or 1.5 μm).

Polarisation resolved measurements of mode structures of Vertical Cavity Survace Emitting Laser Diodes investigated with a SNOM

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Surface emitting laser diodes with verical resonator (VCSEL) gain much interest in the last years. Compared to conventional laser diodes, these new devices have severeal advantages. Two-dimensional laser matrixes of high packaging density can be produced and coupling into optical fibers is possible without complicated optics. Data transfer rates exceeding 40 gbit/s have been demonstrated. Because of the very thin active layer, the light emission of these lasers is longitudinal single mode, although different transversal modes with slightly different wavelenght exist due to their lateral dimension of several micrometer. Because of their high conversion efficiency, the threshold current is very low.

For optical communication purposes, it is very important to know the transversal mode structure and polarisation properties of these lasers. This has been done using a scanning near field optical microscope. An aluminized optical fiber was scanned across the VCSEL and the laser light was coupled into a spectrometer. At each pixel, a highly resolved spectrum was obtained from which the different transversal mode structures of the laser could be extracted. It could be shown, that many lasers are strongly polarized, but some lasers also show local polarization variations.

Reflection-Mode Near-Field Optical Microscopy Using a Scattering Probe Tip

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Recently, the Scanning Near-Field Optical Microscopy (SNOM) has been introduced and developed to overcome the spatial resolution limit classically imposed by the diffraction effect in conventional optics[1]. The value of this limit is about $\lambda/2$ where λ is the wavelength of the light (Abbe barrier).

The SNOM is a Scanning Probe Microscope like STM (Scanning Tunneling Microscope) and AFM (Atomic Force Microscope). However, in the case of SNOM, the optical probe-sample interaction is studied in the near-field zone of the sample surface (that is to say at a nanometric distance from the sample surface).

Generally, SNOM set-up uses aperture probes. These probes are, usually, made from a metal-coated tapered optical fiber which can locally illuminate the sample with evanescent waves or, at the opposite, can also locally detect the evanescent waves generated by the subwavelength sample features. A new family of SNOMs, called 'Apertureless SNOM', has recently appeared[2]. Contrary to the 'Aperture SNOM', which may give a 'direct reading' of the near-field, an apertureless probe can be viewed as an electromagnetic nanoantenna immersed in the near-field of the sample. Its advantages, compared to aperture SNOM, are its high resolution capability, as well as a larger accessible wavelength range[3]. In addition, the use of the already existing AFM, STM and MFM (Magnetic Force Microscope) probes is possible.

We have developed an apertureless reflection-mode SNOM from a commercial AFM device (M5 from Park Scientific Instruments). In this configuration, we use the AFM probe simultaneously as mechanical (AFM mode) and optical probe (SNOM mode). To improve the classical optical resolution, a sharp tip (about 10 nm terminal radius) is mechanically approached very close to the sample surface. Acting as an electromagnetic nanoantenna, the tip end picks up the evanescent near-field generated by the high spatial frequencies ($>>2/\lambda$) of the sample, and converts it into a detectable, propagative far field. In near-field, the resolution is, in first approximation, related to both the tip size and the tip-to-sample distance.

The instrument is polyvalent and allows numerous reflection-mode SNOM configurations. We have undertaken an experimental study of our apertureless SNOM, including the detection process of the SNOM signal as well as polarization contrasts, influence of the angle of illumination and of the angle of detection, and influence of the tip nature on the SNOM contrast. In parallel, the instrument is used both for characterization of components in micro-and opto-electronics, and the study of magneto-optics effects and fluorescence in near-field.

We present the microscope as well as preliminary results demonstrating the capability of our SNOM to provide optical images with a subwavelength resolution. Moreover, a first application in nano-photopolymerization is proposed.

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Are the Illumination and Collection Modes of the Scanning Near-field Optical Microscope Fundamentally Different ?

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On a rigorous theoretical basis, we compare the illumination and collection modes of the scanning near-field optical microscope (SNOM). In illumination-mode SNOM, the sample is locally illuminated by the near field emitted by a small aperture, and the transmitted or reflected light is collected in the far field. In contrast, in collection-mode SNOM the sample is globally illuminated with a conventional optical system, and the near field scattered by the sample is globally illuminated with a conventional optical system, and the near field scattered by the sample is collected by a local probe. Note that the Photon scanning Tunneling Microscope (PSTM) belongs to this second category.

The development of each mode having its own history and its own (sometimes intuitive) motivations, some advantages or drawbacks of a paqrticular mode are sometimes put forward. using the reciprocity theorem for electromagnetic vector fields, we show that the illumaination and collection-mode instruments are equivalent, as far as their imaging properties and potential resolution are concerned [1]

We stress that the result is not trivial, because 1) applying the reciprocity theorem is much more subtle that just reverting the direction of the light (in particular, reciprocity is not equivalent to time reversal), and 2) the reciprocity theorem applies to the *field*, and not to the *intensity*. To extend the theorem to the intensity (i.e., the quantity measured by an optical detector), the *coherence* of the fields must be taken into account. In particular, we need to introduce the concept of coherent, partially coherent and incoherent detection

Reference

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Role of the Probe on Near Field Detection

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A great body of literature has been devoted to the study of the different kinds of optical probes used in near-field optics with experimental setups operating either in the photon scanning tunneling microscopy (PSTM), or in scanning near field optical microscopy (SNOM) configuration [1-3]. Usually, the discussion revolves around the process of fabrication and the analysis of the shape of the tip, and the essential feature of the probe is sometimes alluded to but seldom thoroughly investigated. Indeed, it is most interesting to compare near-field images obtained with different types of probes since the former are a reflection of the near-field interaction between the probe and the electromagnetic field. Simulation of the light detected in near field has already been calculated but not for situations easily comparable with experimental results [4].

After a description of the different kinds of optical probes and of experimental results obtained with these probes we present a comparative study of the formation of the images obtained in the PSTM configuration with different probes. Moreover, the experiments have been conducted on different samples (dielectric and metallic). The role of the physical parameters of the probe are discussed and a comparison between experimental and numerical results is presented.

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A Model for the Spatial Compression of Light to 10 nm Dimensions in the Tetrahedral Tip as a Basis for its Function as a Probe for Scanning Near-Field Optical Microscopy (SNOM)

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The tetrahedral tip can be used as a probe for SNOM and a much higher resolution in the order of 1 - 10 nm is obtained in near field images using this probe [1] than in images taken with probes on the basis of tapered metal coated fibers with an aperture at the end, the most frequently used probes. The body of the tetrahedral tip consists of the corner of a glass fragment. The tip is coated with a thin film of gold such that the three faces of the tip, the edges and the tip itself are covered with gold. Irradiating the tip from within the body of the tip, light emitted from the very tip serves as a nanometric source of light for near field microscopy. The basis of the function of the tip is considered to be a process of light compression, where an incoming beam of light is transformed in three steps to a more and more confined surface plasmon excitation of the metal coating resulting in a very localised excitation of the tip. A qualitative model of this process is outlined. The incoming beam is converted to surface plasmons on two faces of the tip. These surface plasmons travel towards one of the edges where they excite a linear plasmon. The linear plasmon travels along the edge to the tip where a local surface plasmon is exited. Radiation from the tip is used as a local light source for near field microscopy. A theoretical treatment of this process of light compression in the tetrahedral tip is needed for an understanting of the process involved und to find criteria for a further improvement of the performance of the tip.

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Session A04
Wednesday, July 15, AM 08:40-10:20
Room L
Monte Carlo Methods for Propagation and Scattering in Natural Media

Organiser : P. Bruscaglioni
Chair : P. Bruscaglioni

10:20 ***Coffee Break***

An Overview of Monte Carlo Methods for Microwave Satellite Data Simulation

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Recent advances in computer technology coupled with the fact that absorption is fairly strong throughout the microwave, make the Monte Carlo solution of the radiative transfer equation very appealing. All the study presented in this paper started from the necessity to simulate polarized microwave satellite data. Current satellite sensors such as the SSM/I instrument measure microwave brightness temperature (T_B) in both the horizontal as well as the vertical polarization. The analysis of passive microwave associated to Mesoscale Convective Systems (MCSs) [1] reveals the existence of relatively high 85 GHz polarization differences (ΔT_{V-H}) (about 8-13K) over the stratiform precipitation region of both extra-tropical and tropical MCSs and relatively low 85 GHz ΔT_{V-H} (< 6K) over the convective region. The high ΔT_{V-H} could be attributed to atmospheric constituents and, specifically, to non-spherical hydrometeors, such as smaller ice crystals falling slowly with an approximate horizontal orientation in the less turbulent mesoscale updraft. To investigate this point further simulations on realistic cloud models were necessary. With this aim, a new forward Monte Carlo method has been developed for the solution of the radiative transfer equation to include a full treatment of the Stokes parameters. A backward Monte Carlo scheme, even if generally computationally more convenient of a forward scheme, has unfortunately some limitations in its applicability. In the process of obtaining an efficient forward Monte Carlo code, four different Monte Carlo methods have been developed: a backward-forward polarized code for spherical or random oriented hydrometeors, a direct non polarized code, a direct polarized code for spherical or random oriented spheroidal particles and a direct polarized code for oriented spheroidal particles. The aim of these codes is to simulate the radiance that could be measured by a space-borne radiometer, i.e. at the top of the atmosphere in a specific direction and the ultimate goal is to examine quantitatively the effect of non-spherical particles upon the polarization signatures. The Goddard Cumulus Ensemble(GCE) model [2] serves as a realistic hydrometeor field which can be used to study the T_B behavior for varied hydrometeor shape and density assumptions. Numerical results as well as the algorithms description will be presented.

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The Stochastic Process of Transport of Light Through the Atmosphere and Variance Reduction Monte Carlo Simulation of Polarized Multiple Scattering Lidar Returns

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The transport of light through the atmosphere is described as an iterated sequence of collisions, directional scatterings, and changes of frequency and polarization. The collision probabilities are determined by the extinction coefficient. The probabilities for a change of frequency are derived from the relation of the local intensities of the constituents of the scattering ensemble; this is connected with the well-known concept of failure rate in renewal theory. The directional scattering distributions are determined by the polarized phase function which is obtained from the scattering intensities.We get them from the Mueller matrices which determine the single scattering. This stochastic model of the process of multiple scattering of the type of a generalized Rayleigh's random walk is a general and precise mathematical description of the physical process of multiple scattering of light viewed as a 'stochastic corpuscular multiple scattering process'. This approach to transport of light can be shown to be equivalent to the one by the radiative transfer equation.

Starting from this model we derive exact multiple scattering lidar equations including change of frequency and polarization. The Stokes vector of the polarized multiple scattering return signal of a given frequency is given by an infinite sum of (vectors of) complicated iterated integrals, each representing the contribution from a different order of multiple scattering. At present it does not seem to be possible to calculate these integrals describing the contributions of higher orders of multiple scattering exactly, neither analytically nor numerically. Our exact lidar equations allow for calculating the lidar signal by (direct) Monte Carlo methods, but in a very inefficient way only. In order to improve the efficiency of the Monte Carlo simulations, we use variance reduction methods (such as local estimates, scattering splitting, and exponential transform) and we switch from the stochastic model of the type of the generalized Rayleigh's random walk to a much more complicated stochastic model of a 'stochastic multiple scattering cascade process with polarization and change of frequency' which describes the variance reduction methods, reproduces the exact multiple scattering lidar equations, and guarantees (relatively) fast calculation of the lidar return signal including all orders of multiple scattering. The precision of the calculation is controlled by the empirical variance of the Monte Carlo simulation; this variance may be chosen as small as wanted.

We shall show some results of simulations of polarized return signals of a ground-based and a space-based lidar system from clouds of nonspherical particles such as hexagonal columns, dendrites, and bullet rosettes. Furthermore, we shall show some results of the simultaneous retrieval of the extinction coefficient and the size distribution. This retrieval method is based on the variance reduction Monte Carlo method and search procedures and yields a sensitivity analysis of the retrieval.

Multiple Scattering Effect for Spaceborne Lidar

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Multiple scattering contributions to lidar measurements from clouds, and domain of the atmosphere hidden by the clouds, alter well determined single scattering shape of range resolved power from the cloud structures. Resolution of the lidar sensor is reduced by pulse stretching effects, the reflectance is increased by multiple scattering.

On basis of variance reduction Monte Carlo method [1] multiple scattering effects for a lidar system, flying on-board a polar platform satellite, to profile vertical structures in multilayered clouds including high level semitransparent cirrus layers, aerosols and lower level water clouds are assessed.

The lidar signal is very sensitive to fine stratifications in crystal and mixed phase clouds as in cirrus, as well as to vertical distributions of underlaying aerosols [2]. For horizontally homogeneous cirrus clouds (allowing for accumulation over series of pulses) geometrical parameters as cloud top height, sublayers heights, and base height are directly retrieved from the lidar multiple scattering signals. The signals from layered structures in dense water clouds are stretched over resolution bins by multiple scattering.

Strong depolarization effects in dense water clouds are caused by contributions of high scattering orders. Saturation of a depolarization ratio is observed for high particle densities. Due to forward peaked scattering of light by large crystal particles, values of lidar depolarization ratio for single and multiple scattering are close to each other for pure crystal as well as for mixed phase clouds.

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Raman lidar and multiple Mie scattering

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In the Raman-Lidar technique Raman return from, say, N_2 is separated from elastic scattering return (Mie or Rayleigh), due to aerosols or molecules, by means of interferential filters.

Mie scattering by aerosols produces exponential attenuation. On the other hand, multiple scattering within the cloud can give rise to a counter-effect increasing the intensity of Raman return.

Similar effects can be present for the Rayleigh Lidar (High Resolution Lidar Technique).

A version of the Monte Carlo code has been developed to examine this point. One condition is introduced in the code: along each trajectory contributing to Raman return only one molecular scattering is allowed to occur, due to the very small molecular scattering coefficient in comparison with the Mie coefficient inside the cloud. Multiple molecular scattering is thus negligible, while multiple Mie scattering can be significant.

We refer to an atmospheric stratified models: three principal layers are considered. The first one is a pure molecular atmosphere, the second one is limited by the lower and the upper limit of a homogeneous cloud and the last one is again a pure molecular atmosphere.

The cloud models used are C1-Deirmendijan models.

The pure molecular atmospheric layers are optically characterised by a molecular phase function $p_M(\theta)$ (where θ is the scattering angle) and by a linear extinction coefficient $\sigma_M(z)$ obtained from the numerical concentration N(z) and the molecular scattering Cross Section Cs. In the same way, the extinction coefficient of the cloud layer is a sum of the molecular (M) and water droplet (W) extinction coefficients ($\sigma_T(z) = \sigma_w + \sigma_M(z)$). Finally, the phase function is a mixture of molecular (M) and water droplet (W) phase functions according to the relative extinction coefficient :

$$p(\theta) = \frac{\sigma_M}{\sigma_M + \sigma_W} \cdot p_M(\theta) + \frac{\sigma_W}{\sigma_M + \sigma_W} \cdot p_W(\theta)$$

When a scattering event occurs inside the cloud, at height z, the probability of having a molecular scattering is $P_M = \frac{\sigma_M}{\sigma_M + \sigma_W}$ and the probability of having a particle scattering is $P_W = \frac{\sigma_W}{\sigma_M + \sigma_W}$.

According to the calculated probability P_M and P_W, the code 'decides' if the actual scattering point is a molecular or Mie scattering point. In the first case, to describe the angular scattering characteristics, the molecular phase function $p_M(\theta)$ is used. In the second case the Mie phase function $p_W(\theta)$ is applied to determine the direction of scattering. For each trajectory only one molecular scattering is considered.

Polarization Lidar for Cloud Study from Space : Monte Carlo Techniques and Simulations

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The basic technique of the polarization lidar to discriminate water and ice clouds is based on the scattering theory. Spherically symmetrical scatterers such as water droplets produce no depolarization of the incident radiation in the exact backscattering direction [1]. The droplets backscatter calculated from the Mie theory is a combination of axial and paraxial reflections which do not change the incident polarization state given by the Stokes vector.

In liquid water clouds sounded with a monostatic lidar the variation of the Stokes vector of a laser pulse is due to multiple scattering contributions. Beside the other main effects as pulse lengthening and beam spreading, the depolarization due to the multiple scattering is an important factor for any kind of dense clouds.

The backscatter from non-spherical ice crystals is given by internal reflections that rotate the incident polarization plane leading to the depolarization in the backscattering direction. The depolarization of laser radiation backscattered by non-spherical ice particles has been observed in the laboratory and remote sensing experiments.

Features of Monte Carlo techniques to evaluate the cooperative effects of multiple scattering and the non-spherical shapes of the ice crystals for a spaceborne polarization lidar are presented.

Contributions of high scattering orders from dense water clouds cause a saturation of a depolarization ratio.

Radiation scattered by large crystal particles show Fraunhofer diffraction peak. As a consequence of this anisotropy of scattering, lidar multiple scattering polarization components consistent with measurement geometry, instrumental parameters, and optical characteristics of scattering targets, are not negligible.

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Session A05
Wednesday, July 15, AM 10:40-13:00
Room 300
Surface Scattering Theory

Organiser : M. Saillard
Chair : M. Saillard , J. A. De Santo

Study of Scattering from Rough Multilayers Application to the Design of Light Absorbers

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It is well known that the scattering from a rough surface can be modified by covering it by one or more layers of different opto-geometrical characteristics (thickness, refractive index). A lot of theoretical and experimental work has been done to study scattering from multilayer coatings for thin films applications [1], [2]. The study of this phenomenon has been carried out in the case of smooth surfaces for both cases of surface scattering and bulk scattering[3]. Theoretical results obtained with first order vector theories and experimental ones have shown that coatings can be used to reduce scattering [4]. The extension of this work to the case of randomly rough surfaces requires the use of a rigorous method. Recently some results have been presented (for detecting subsurface bodies) in the case of randomly rough multilayers with an homogeneous region between each interface[5]. It appears that the surface integral method is well adapted to the study of scattering from this kind of structure. However, due to increase of unknowns, the surface integral method cannot be used when structures with a high number of rough interpenetrating layers are considered. In order to solve this problem, a method based on the differential formalism has been recently developed [6]. This method, which permits one to treat surface scattering and bulk scattering in the same way [7], can be used to study scattering from randomly rough interpenetrating multilayer structures. One of the most challenging applications of this study is the design of light absorbers for eliminating parasitic light. The performances of these components are critical in many optical systems and the study of black coatings made with rough absorbing paints is of topical importance [8]. We show that the deposition of one or more dielectric thin films on black paints with standard performances (Total Integrated Scattering (TIS) close to 4%) can reduce scattering by a factor 10, resulting in an absorption of 99.8 %. We show that the refractive index of the bare surface can be determined by comparing the numerical results to the experimental ones. The components have been characterized with our scatterometer [9] and checked with an atomic force microscope. We show that a very good agreement between experimental results and numerical ones has been obtained. A numerical study of the effects of multilayer coatings deposited on surfaces with different roughnesses is also presented.

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Coupled Volume and Surface Scattering by Random Systems

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Scattering by random rough surfaces has attracted a lot of attention in the last ten years. Yet, only a few works deal with coupled scattering due to both rough surfaces and volume scatterers. The goal of the present paper is to report on recent work on this topic by using both an approximate approach and exact numerical simulations.

In order to deal with this type of problem the Mean Field Theory is particularly well suited. Indeed, surface scattering is described as a scattering phenomenon due to the randomly fluctuating dielectric constant, just as for volume scattering. Thus, MFT provides a natural framework to deal with the coupled scattering problem. It enables to derive a simple explicit expression for the scattered intensity.

The results are compared with numerical simulations based on an integral formulation of the problem solved by means of the moment method. We also compare the results with an algorithm based on the differential formalism.

The results show that volume scattering and surface scattering can be separated and described separately for dielectric surfaces with dielectric inclusions. A quantitative comparison of the magnitude of both mechanisms is given.

Exact Computation of a 2-D Volume and Surface Scattering Problem

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Volume scattering by random media is a problem that can be solved in two different ways: one can solve either the Radiative Transfer Equation or perform a Monte Carlo average of numerical simulations based on Maxwell equation in order to determine the Bidirectional Reflection Distribution Function (BRDF). In this communication, we report on the development of a periodic integral method being used to compute the fields.

The choice of a periodic method allows us to study an infinite problem avoiding edge effects. The exact method used to solve each problem is based on the Floquet theorem. A classical integral method is used to solve the bounded problem of the scattering in the unit cell of periodicity, including the region near the surface where the Rayleigh expansion is no more valid. Finally, we solve the problem with the well-known Method of Moments.

The period must be chosen large enough so that the interaction between a scatterer and its translated image is negligeable. As the problem is periodic, the diffracted field is a sum of plane waves. The bidirectional reflection coefficients can then be averaged over the geometries studied which lead to a specular component and to the BRDF.

The method is able to deal with surface problems or volume problems. It can also compute the field when there is coupled surface and volume scattering. Its limitation is the size of the matrix problem and the CPU time that is needed to compute hundreds of geometries. In this case, the problem can be splitted in smaller ones.

Scattering Computations for a Perfectly Reflecting Grating

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We discuss the scattering of acoustic or electromagnetic waves from one-dimensional rough surfaces [1]. We restrict the discussion in this report to perfectly reflecting Dirichlet surfaces (TE-polarization). The theoretical development is for both infinite surfaces and periodic surfaces, the latter equations derived from the former. Several theoretical developments are presented. They are characterized by integral equation solutions for the surface current or normal derivative of the total field. All the equations are discretized to a matrix system and further characterized by the sampling of the rows and columns of the matrix which is accomplished in either coordinate space (C) or spectral space (S). The standard equations are referred to here as CC equations of either first kind (CC1) or second kind (CC2). Mixed representation equations or SC type are solved as well as SS equations fully in spectral space. Remarks are also included about wavelet techniques used to solve the integral equations. These have generated some recent interest for electromagnetic scattering from simple shapes. Our conclusions for rough surface scattering differ somewhat from the literature conclusions.

Computational results are presented for scattering from various periodic surfaces. The results include examples with grazing incidence, a very rough surface and a highly oscillatory surface. The examples vary over a parameter set which includes the geometrical optics regime, physical optics or resonance regime, and a renormalization regime. Results of wavelet applications are also included as well as the Fourier transform of the periodic Green's function.

The objective of this study was to determine the best computational method for these problems. Briefly the SC method was the fastest but did not converge for large slopes or very rough surfaces. The SS method was slower and had the same convergence difficulties as SC. The CC methods were extremely slow but always converged. The simplest approach is to try the SC method first. Convergence, when the method works, is very fast. If convergence doesn't occur then try SS and finally CC.

Reference

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Influence of Dielectric Constant and Losses on Electromagnetic Scattering of a Fractal Profile

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Applications for Ultra Wide Band radars include detection of targets set on or buried under the soil interface, and for designing such radar it is important to be able to predict the response of rough surfaces. Consequently, when dealing with short electromagnetic pulses and natural media, one is interested in models of clutter relevant for all the scales included in the pulse spectrum. Fractals may then be appropiate because of their multi-scale behaviour. In previous works, they have shown to be pertinent models for representing real rough surfaces using Weierstrass functions. Fractal dimension has also proved to be a pertinent discriminating parameter, which is transmitted to the time domain scattered field in the case of a PEC profile. In this case, electromagnetic computation was performed by using method of moments in the frequency domain followed by an inverse Fourier transform, which generates the time domain response subsequently processed by the Box Counting method.

It is interesting to see how these results evolve when the rough surface is dielectric, lossy or not. Indeed, in this case, pulses interact with roughness with penetration and volume effects which gives rise to more complicated scattering processes and introduces as well absorption. For this, Finite-Difference Time-Domain method has been implemented and permits to evaluate in the far zone both the backscattering coefficient, deduced with a Monte Carlo process, and the time domain scattered field. In the presentation, we will show simulation results pointing out the influence of fractal parameters of the profile on the electromagnetic scattered field, as a function of the constitutive parameters of the subsurface medium assumed homogeneous. Influence of losses will be particularly investigated.

Diffusion of Electromagnetic Waves from Rough Inhomogeneous Films. Study of the Coupling Between Surface and Volume Scattering

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Volume and surface scattering is of topical importance in geophysics for microwave sensing of ocean surfaces, soils or snow but also in optics where the origin of the diffusion losses has to be determined in order to improve the efficiency of the components. Mostly approximate models, such as Born approximation or perturbation theory, have been developed to address this difficult issue. In this work, we present two complementary approaches that are based on rigorous formulations of the Maxwell equations.

Owing to a mixed representation in coordinate and spectral domains, the boundary integral formalism has been adapted to handle the problem of scattering from one-dimensional rough surfaces with many randomly placed inclusions [1] [2]. This technique accounts for all the interactions between the scatterers and the surface but is limited (for numerical reasons) to diffusers of small size. We present a study of the differential reflection coefficient for various rms heights, correlation lengths and density of the embedded scatterers. It is shown that, in certain cases, one can separate the contributions of volume and surface scattering. The problem is thus considerably simplified.

We have also adapted the rigorous differential formalism [1], well known in the grating domain [3], to calculate the scattering from one-dimensional rough films with inhomogeneous dielectric profiles. Owing to the representation in the spectral domain of the permittivity, the differential method allows us to study geometries with continuously varying refractive index. We present numerical simulations of the diffusion pattern of rough surfaces with inhomogeneous permittivity (corresponding to horizontally or curvy stratified media such as soil or snow) for various rms heights and correlation lengths. The influence of the volume variations of the permittivity and of the surface roughness on the differential reflection coefficient is investigated.

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Electromagnetic Wave Localization in Disordered Finite or Infinite Media : Analysis of the Localization Criterion

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The purpose of this paper is to study the wave behaviour in disordered media. The analysis focuses on the localization of classical waves in 3D for scalar waves (optical waves) and vectorial waves (electromagnetic waves).

In the first part of the paper we consider the behaviour of an electromagnetic wave or an optical wave in a dielectric medium containing randomly distributed metallic or dielectric spheres. The random distribution of the spheres is uniform. The dielectric volume is infinite and filled with N spherical scatterers. We use diagrammatic Green's function method to investigate the criterion for the localization of the classical waves. We know the wave acquires a diffuse behaviour inside the medium. A perturbative calculation of the averaged intensity gives us the expression of the diffuse coefficient D. When the medium is supposed to be macroscopically homogeneous, D can be written as $D = D^B(1\text{-}c)$ where D^B is the classical Boltzmann coefficient, c is a term including the effects of wave retrodiffusion. Localization occurs when D=0, this equality means $k_e.l < \sqrt{\frac{3}{\pi}}$, k_e is the wavevector in the effective medium, l the diffusion length of the wave. Then, we compute k_e and l using a single and *double* scattering approximation for an uniform distribution of N spheres inside a dielectric medium. The actual scattering involved is not underestimated by the double scattering approximation. The $k_e.l$ product is governed by a set of parameters: density of scatterers, nature of scatterers (radius, permittivity), wavelength. We can then find a condition of localization, i.e. a range of values satisfying the criterion $k_e.l < \sqrt{\frac{3}{\pi}}$.

In the second part of the paper, we give new results concerning a gaussian distribution of spheres in infinite disordered media. Due to the lost of homogeneity of the whole medium, we cannot express a localization criterion. Then we try to verify the fact that one way to facilitate the localization of 3D classical waves is to start with a periodic system of metallic spheres and then add randomness to it. We analyze the condition of localization in this system. Finally we investigate the condition of localization for finite slabs and finite spherical volumes. We verify the influence of the thickness of the slab or the radius of the volume on the condition of localization.

The third part of the paper consists of numerical simulations of the different systems we have examined. We analyze the different parameters of the systems (distribution of the scatterers, radius of the spheres, permittivity and conductivity of the scatterers and the medium, wavelength...) satisfying the condition of localization. We confirm the possibility of localization of classical waves in 3D.

Session B04
Wednesday, July 15, AM 08:40-12:20
Room G/H
Non Linear Inversion : Algorithms and Applications

Organiser : R. Pierri

Chairs : R. Pierri, O. M. Bucci

Image Reconstruction from TE Scattering Data using Strong Permittivity Fluctuation Theory

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The nonlinear relationship of the scattered field to the object function to be reconstructed often limit the range in which nonlinear inverse scattering methods can be applied. In this talk, we will discuss the use of the strong permittivity fluctuation theory in mitigating this nonlinear relationship. It has the same spirit as the local shape function method in reducing nonlinearity in the inverse scattering problem. Compared to the TM case, the inverse scattering problem for the TE incident field is more complicated, due to its stronger nonlinearity. This work provides an effective method for the reconstruction of 2D inhomogeneous dielectric objects from TE scattering data. The algortihm is the combination of distorted Born iterative method and strong permittivity fluctuation theory. Numerical simulations are performed and the results show that distorted Born iterative method for strong permittivity fluctuation (SPF-DBIM) converges faster and can obtain better reconstructions for objects with larger dimensions and higher contrast in comparison with ordinary distorted Born iterative method (DSBIM). Frequency hopping technique is also applied to further increase the contrast that can be reconstructed.

High Resolution Processing Algorithms for Near Field Object Detection : Performance Bounds and Sensitivity Analyses

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A common problem in many application areas is the detection and localization of targets with known structure based on observations of scattered electromagnetic or acoustic fields. In recent years, there has been considerable work in methods for solving such problems in a manner which bypasses the need to solve a large, ill-posed inverse scattering problem. These processing methods extract from the data a small number of geometric parameters describing the target distribution. In previous work, we have considered algorithms of this type for locating targets in the nearfield of a linear receiver array. Initial results based on the use of high resolution array processing techniques indicate that these methods provide highly accurate localization of arbitrary collection of buried metallic and dielectric objects.

In this paper, we examine issues of performance and sensitivity analysis associated with these processing methods. Because our techniques are statistical in nature, we are able to develop explicit expressions for the error variance (or bounds on this quantity) which provide hard limits on the best performance achievable from the use of these array processing techniques. We show that these bounds are easily and elegantly obtained when one employs a T-matrix model to describe the scattering processes.

A key assumption underlying the success thus far of our methods is that we know the number of targets for which we are looking as well as their material properties. In this paper, we explore the sensitivity of our localization techniques to show how our detection schemes behave when the actual parameters are different from the ones used in the algorithm. For example, we determine the degradation in performance when the actual shape of the target differs from the one the algorithm assumes. Of particular interest are sensitivity to changes in target shape and material properties. We establish analytical bounds for sensitivity against changes in these parameters, and verify these bounds with Monte-Carlo runs.

In addition, we determine "detectability" of targets for a given geometry. For example, we find the minimum radii of objects for a certain soil type or minimum distance between two objects to achieve a particular detection probability for a fixed false alarm rate. In the talk, we will show examples of sensitivity analyses and detectability problems for multiple mine-like and drum-like objects.

Some Uses (and abuses) of Reciprocity in Wavefield Inversion

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Reciprocity plays a curious role in the analysis and solution of inverse problems for electromagnetic wavefields. It is fundamental—since all practical results in wavefield inversion can be derived from reciprocity theorems. And it is superfluous—since these same results can always be obtained without any explicit mention of reciprocity. We explore these two "states" of reciprocity by considering some of its uses in wavefield inversion and pointing out what (we think) is its proper role and why it is often overlooked or misconstrued.

A convenient way of bringing reciprocity into wavefield inversion is to first derive equations for the partial derivatives of field quantities with respect to medium properties. These equations follow from taking appropriate Frechet or partial derivatives of Maxwell's equations. The fields and their partial derivatives can then interact in reciprocity theorems, of both correlational and convolutional type, to produce elegant formulas (and fast algorithms) for computing quantities that are needed to drive a nonlinear inversion. Convolutional reciprocity theorems give partial derivatives with respect to medium parameters (electrical conductivity, magnetic permittivity, or magnetic permeability) directly; a generalization gives derivatives with respect to parameters defining the geometry of a model.

Correlational reciprocity applied to a partial derivative field and a time-reversed adjoint field gives a formula for the gradient of the error functional (e.g., the sum of squared errors) measuring the mismatch between computed and measured quantities. This formula requires only two forward modeling runs to compute the gradient: one to compute the fields in the current model and a second to backpropagate the residual (scattered) field in reverse time through the model. The value of the gradient at any point in the model is the correlation of these two fields at that point. This formula for computing the gradient resembles the prescription for imaging acoustic wavefields called seismic migration. It *becomes* the (electromagnetic equivalent of the) formula for seismic migration when the error functional is taken to be the flow of power—i.e., the flux of the Poynting vector—of the residual field across the surface where measurements are made. Gradient algorithms and seismic migration provide only approximate inverses of the equations of linearized scattering (Born approximation). These approximate inverses can sometimes be improved dramatically by a small modification that amounts to a pre-filtering of the data or post-filtering of the image. Full linearized inversion about an arbitrary background model remains a enormous computational challenge.

Nonlinearity and Multimodality in Inverse Problems

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Imagine two different likelihood functions (or Bayesian posterior probabilities), one has a null-space and the other has some local extrema. Suppose we select a number of initial models (points in the domain of these functions) at random and perform local optimization on them. (For instance, to compute a maximum likelihood or maxium a posteriori model.) In both cases, after a certain number of iterations we will observe the lack of convergence to a central model.

In fact, if we do not monitor the convergence closely we might confuse the two situations, local extrema versus null space effects.

From the standpoint of inverse theory the interpretation we would give the two cases is completely different : a unimodal function which is flat in some direction would be well-described by giving the mean and variance, concepts that could be completely irrelevant in the presence of local extrema. This means that for nonlinear, multi-modal inverse problems, some characterization of the topography of the misfit function is essential. We must know not only the number of local extrema, but also whether these extrema are deep (and therefore represent potentially important model features) or shallow (in which case they are irrelevant). I will show examples of various real-world inverse calculations and discuss how the topography of high-dimensional functions influences the inferences that one makes.

Reconstruction of Underground Tunnel by using FDTD method and the Genetic Algorithm

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Detection of isolated target such as deep underground tunnel may be possible by the cross-borehole measurements. In-situ permittivities and conductivities of the underground medium may be obtained by three borehole measurements; one for the transmitting(source) short dipole antenna and the others for the receiving antenna picking up the scattered fields at two different distances. By taking the division of these two fields, one may obtain the permittivity and the conductivity from the ratio of the amplitudes and the difference of the phases, respectively. The tomograms of permittivities and conductivities distribution are obtained from the in-situ data measured by Ra-Geovis, the continuous electromagnetic wave underground radar, by using the multi-frequency averaging and the backprojection.

The isolated target such as the air tunnel, however, produces fluctuating interference fringes of permittivities and conductivities near the target, even with the multi-frequency averaging. After identifying the isolated target from this tomogram and by defining the region of reconstruction, one may reconstruct the complex permittivities of the isolated target by using the iterative inversion method. Genetic algorithm plus Levenberg-Marquardt algorithm is used to find the global minimum of the cost function, where cost function is defined as the squared magnitude of the differences between the measured fields and calculated fields from iteratively chosen dielectric profiles. Two-dimensional FDTD numerical method is used with the summation over discretized spatial frequencies along the tunnel axis to account for the three-dimensional short dipole radiation and the scattering by the two-dimensional tunnel. Multi-frequency scattered fields are obtained via the Fourier transform of the time-transient pulsed scattering fields. An air tunnel of about 2m diameter at the depth of 75m is reconstructed by the above method from the measured fields of 11 frequencies from 10MHz to 50MHz with 4MHz step and 51 measurement points along the borehole, which shows clearly the existence of this high contrast tunnel object in the pretty homogeneous background medium.

Inverse Scattering for 2-D Buried Obstacles : Comparison of the TM- and TE-Cases

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The determination of geometrical and/or physical parameters of an obstacle embedded in a lower half-space and illuminated by a set of time-harmonic sources placed in the upper half-space from the observation of the electromagnetic field along a probing line in the same half-space, is a challenging inversion problem which is to be faced in many applications of interest (electromagnetic nondestructive evaluation of defects affecting a material slab, characterization of a target buried in soil using a ground probing radar, etc.). However so far most investigations of this nonlinear and ill-posed wavefield inversion problem —ill-posedness here is strongly enhanced by the limited aspect of the observation since one cannot illuminate the obstacle from all around and is only partially offset by gathering data at several frequencies in a given frequency band— are limited to developing and testing one specific algorithm tailored for one specific geometric and data configuration, without enough effort devoted to comparisons of algorithms or to extensions beyond that peculiar configuration.

Here the aim is to illustrate the behavior of a whole family of nonlinearized iterative inversion methods, the so-called modified gradient algorithms. As is now well-known, such algorithms are constructed from a contrast-source domain integral formulation established from the Helmholtz wave equations satisfied by the fields by application of the Green's theorem, and they aim at the minimization of a cost functional made of the error in satisfying a so-called state equation, which links the field in a prescribed test domain to itself and to an appropriate contrast function, and the so-called observation equation, which links the data to those predicted for given field and contrast in the test domain. They use the bilinear aspect of the scattering problem with respect to the wavefield and to the contrast function, and are versatile enough to accommodate diffusive or propagative wavefields (e.g., at eddy current or microwave frequencies) of various polarizations (e.g., TM and TE as seen below), positivity constraints (e.g., of the real and imaginary parts of the contrast when using a Maxwellian model), or binary constraints (the material parameters of the obstacle are known of constant value but their distribution in space is unknown).

For simplicity here, we limit ourselves to the retrieval of a buried cylindrical obstacle of axis parallel to the interface and of bounded cross-section, and we assume that the embedding half-space and the obstacle materials are linear, isotropic, nondispersive lossy or lossless dielectrics that are characterized at a given space point by their relative permittivity and their conductivity —notice that the obstacle may be a stronger or a weaker scatterer than its embedding, which is in contrast with free-space electromagnetic inversion. Canonical cases of linear polarization of the incident wavefield due to line sources placed at several locations above and parallel to the interface, are considered: TM and one uses a scalar formulation of the resulting single-component electric field, TE and one uses a scalar formulation of the resulting single-component magnetic field, with emphasizing that discretization in the second case is far more demanding notably in terms of the complexity of the required basis functions. Results of the inversion of noiseless and noisy, multi-frequency, multi-source test data —which are generated with meshes appropriately finer than those of the inversion procedures so as to reduce the inverse crime— are then discussed for a variety of obstacles with emphasis on comparisons between such TM and TE polarization cases.

Formal Compensation of Sensor Related Interactions for Quantitative Microwave Tomography

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Past publications concerning microwave tomography refer to multiple illumination measurement schemes (multifrequency and/or multiple incidences), which do not take into account, for the reconstruction, the perturbing presence of the sensors in the testing area. At most, the measured scattered field at the sensors locations is supposedly linearly related to the field they perturb. For practical reasons, especially for free space configurations instead of trying to built low perturbation sensors, thus expensive and poorly sensitive ones, one can think of using common sensors, thus inexpensive, sensitive, but perturbing ones, and include them theoretically into the reconstruction formalism itself. The reconstruction formalism used here is based on a Newton-Kantorovich technique which, starting from an initial distribution of the contrast, iteratively minimizes the difference between the measured scattered field and the scattered field calculated from a numerical model.

In order to get back to the classical formalism developed in [1], an electrical field integral equation (EFIE), including the interaction between the object and the sensors, and the interaction between sensors themselves is used as a starting point. The concept of equivalent scattered field is introduced and is defined as such as it formally compensates all the sensor related interactions.

The formal compensation procedure has been numerically implemented. From the EFIE, equivalent coupling and observation equations are derived by applying the method of moments. By differentiation of these equations to the first order, an analytical expression of the derivative matrix relating the correction of the contrast to the corresponding perturbation of the equivalent scattered field is obtained.

The procedure has been validated on a highly contrasted inhomogeneous cylinder illuminated by a TM polarized plane wave, and sensors were modeled by metallic wires.

It is therefore possible to include the sensor interactions into a quantitative reconstruction process. Note that this procedure offers more flexibility in modeling various experimental configuration, and thus increases the fields of microwave tomography applications.

Directions for future work include the modelization of other types of sensors related to experimental cases, the testing of the new procedure on real data, and the development of the three-dimensional vector case.

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3-D Joint D.C. Resistivity and Seismic Refraction Tomography

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Although electrical and seismic properties in the Earth are not directly associated with each other, they are related to the same geological structures. If a large contrast in seismic velocity occurs across a geological interface, certain changes of the corresponding electrical properties may also very likely take place, but not necessarily. Conventionally, the results of separate seismic and electrical modeling are combined to infer geological structures. Such an approach is called "Integrated Geophysics." In this study, we advance one step further in making maximum use of multiple geophysical data, i.e., from "Integrated Geophysics" to "Joint Geophysics." We simultaneously invert resistivity and seismic data and ensure maximum structure coherency between two different physical properties during inversions.

This joint tomography approach includes a 3-D D.C. resistivity inversion method and a 3-D seismic refraction traveltime inversion method. The 3-D D.C. resistivity method applies a transmission-network analogy for the forward electrical-potential calculation (Zhang, Mackie, and Madden, 1995). The 3-D seismic refraction traveltime tomography includes a rapid wavefront raytracing method for traveltime and raypath calculation (Zhang and Lavely, 1997). A nonlinear conjugate-gradient optimization method is applied to solve an inverse problem that minimizes the seismic traveltime and electrical potential misfits and, meanwhile, maximizes coherency of their normalized structure curvatures by way of Tikhonov regularization.

Seismic velocity and electrical resistivity represent two different physical properties of the Earth's materials. They have no direct and quantitative relationship. However, the curvature variations of these properties are likely associated with the same geological discontinuities. In the joint inversion approach, therefore, the curvature variations of the two properties are mutually constrained rather than the properties themselves while fitting both types of data.

We demonstrate the performance of the joint tomography technique with numerical examples, as well as, real data for characterizing 3-D shallow geological structures.

Optimization Approach to Reconstructing 2D Dielectric Objects

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A common strategy for solving nonlinear inverse problems is to apply an iterative procedure based on a local linearization around some "best estimate", which is either an initial guess or the result of a previous iteration step. In this context, the field inside the scattering object is considered as a function of the variables that represent the unknown constitutive parameters. The key issues in the application of such iterative schemes are the "dynamic range", i.e., the range of parameters over which the scheme converges, and the "resolution", i.e., the detail with which the unknown object can be reconstructed. In previous work [1,2], the last two authors have studied these issues for the problem of determining the susceptibility profile of a two-dimensionally inhomogeneous, lossless dielectric cylinder embedded in free space. Both aspects were studied by applying the distorted-wave Born approximation to specially chosen configurations. The conclusion was that linearization-based techniques can be used to reconstruct objects of large contrast with a given resolution, provided that multiple-frequency information is available.

Inversion procedures of the type described above are only feasible if a fast algorithm is available for solving the direct-scattering problem for successive estimates of the unknown configuration. In our implementation, a contrast-source integral equation with a free-space reference medium is solved by the CGFFT procedure. For the space discretization, we follow the approach outlined in [3]. The discretization procedure is second-order accurate in the space step preserves the convolution-type structure of the continuous equation, and can handle boundary information. The initial estimates for the CGFFT procedure are generated with the aid of the extrapolation procedure proposed in [4].

As mentioned above, the applicability of linearized methods depends critically on the validity of the linearization. Further, the computational effort required to solve the linearized equation(s) for the "profile update" in each iteration step is comparable to that spent in solving the approximate forward problem for multiple excitations. This has led to the idea of replacing this "update step" by a line search in a nonlinear optimization procedure. By "marching on in search direction", we can then use the same combination of the CGFFT and extrapolation procedures to compute the field information that is needed for the repeated evaluation of the cost function.

In this contribution, the basic ideas of such an approach and the possibilities for its implementation will be discussed, and the first numerical results of reconstructing the configuration considered in [1,2] will be presented.

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Quadratic and Quadratic Iterated Approaches to Inverse Scattering

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The problem of reconstructing the dielectric contrast profile of a two dimensional dielectric cylinder from scattered field measurements is, as well known, a non linear ill posed problem. A method to deal with it consists in expanding the contrast by a finite set of basis functions and in looking for a finite number of unknown coefficients by minimising an error function. Generally, this error function presents several local minima, traps for the inversion procedure.

A widely used simplification is obtained by linearising the operator mapping the contrast onto the scattered field. However, a linear inversion does not allow to reconstruct spatial variations related to the higher order functions of the Singular Value Decomposition (SVD) of the linearised operator since the singular functions corresponding to the lower singular values have a negligible image. This generally provides limitations on the reconstruction of rapidly varying profiles.

Recently, a new approach based on a quadratic approximation has been considered [1] and its capability of retrieving a wider class of contrast profiles with respect of the linear inversion methods has been shown.

On the other hand, the quadratic approach provides an error function of the fourth order that can show local minima. However, an insight on this subject [2], has shown that by increasing the number of independent measurements with respect to the number of unknowns the error function has only one (global) minimum.

In this paper we mean to extend the quadratic inversion approach to the iterated method, where at each step only the difference with respect to the contrast function found at the previous iteration is searched for. This procedure can enlarge the class of reconstructable profiles.

Examples of reconstruction for a circular dielectric shell, making use of a multiview plane wave TM incident field, provide a comparison between the performances of the quadratic iterated and the linear iterated inversion algorithms, starting from the same initial point. Results show the capability of the quadratic approach to retrieve rapidly varying functions, opposite to a diverging behaviour of the linear approach.

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Session C04
Wednesday, July 15, AM 08:40-11:20
Room I
Selected Topics in Computational Electromagnetics

Organiser : J. T. Aberle

Chairs : F. L. Whetten, D. B. Davidson

FDTD Prediction of Penetration Into an Airliner

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As the complexity and criticality of the functions performed by the electronics on-board civilian transport aircraft increases, so does concern about the vulnerability of these systems to electromagnetic interference (EMI). Sources of EMI that are of particular concern are man-made radio frequency (RF) sources generated external to the aircraft, such as radar and radio transmitters. These potential sources of EMI are collectively known as HIRF or High Intensity Radiated Field sources. The National Aeronautics and Space Administration (NASA) has become concerned about the threat that HIRF poses to the safe operation of civilian airliners and is funding investigations to find ways to quantify and reduce this threat.

In 1995, the NASA Langley Research Center conducted a series of aircraft flight tests aimed at characterizing the internal electromagnetic environment (EME) to which onboard equipment are subjected during flight. The test object for these flight tests was a commercially configured Boeing 757 owned by NASA. This aircraft was instrumented with an array of sensors positioned so as to study the electromagnetic coupling characteristics and shielding effectiveness of the aircraft's three main compartments; the flight deck, the avionics bay, and the passenger cabin. Measurement data were collected as the aircraft performed a series of flights over fixed-frequency RF transmitters operating in the HF, VHF, and UHF frequency bands.

The data from these flight tests were collected with the intent that they be used for the validation of techniques for the prediction of the EME inside aircraft. Validated EME prediction techniques could, for example, provide avionics designers knowledge about the effects of HIRF threats on the internal EME early in the aircraft design process. Such knowledge would improve the design process, resulting in more robust and cost-effective designs. This paper reports on efforts to develop FDTD-based EME prediction techniques and compares prediction results with the data collected by the flight tests. The size and complexity of the physical object modeled presents a number of challenges to FDTD modeling that will be discussed here.

On the Behavior of Electromagnetic Fields in the Anisotropic PML

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The anisotropic perfectly matched layer (PML) was developed as an alternative to the original split-field PML technique. The anisotropic PML does not require modification of Maxwell's equations, and is particularly well suited for use in frequency-domain finite-element and finite-difference methods. Unfortunately, there are several misconceptions about the anisotropic PML which appear to be widely accepted in the community. These misconceptions are [1] that the PML works by causing the refraction angle in the PML to be equal to the incident angle in the actual medium for all angles of incidence, and [2] that the reflection coefficient at the boundary of a conductor-backed PML can be reduced for a propagating wave by increasing the real part of the complex characteristic parameter of the PML.

In this contribution, we discuss the behavior of electromagnetic waves within a PML, and dispel the common misconceptions. We also demonstrate the validity of the following conclusions :

References

[1] The velocity of propagation of an electromagnetic wave in the PML is a function of the incidence angle.
[2] The PML is perfectly matched because the variation in velocity versus incidence angle exactly compensates for the variation in refraction angle versus incidence angle.
[3] The real part of the PML parameter affects only the phase of the reflection coefficient at the boundary of a conductor-backed PML.
[4] The imaginary part of the PML parameter affects only the magnitude of the reflection coefficient at the boundary of a conductor-backed PML.

A Generalisation of the PML with Application to Biaxial Materials

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The perfectly matched layer (PML) is an artificial material that has been used as an effective means for truncating the computational space in many finite methods. The PML can be arranged such that it matches an adjacent dielectric material, ensuring that, ideally, there is no reflection from the interface. In numerical applications, a thin layer of lossy PML is often placed around the boundary of the solution domain. Fields that are incident on this PML boundary pass through the interface and are then rapidly absorbed. The PML region may then be truncated by the tradition Dirichlet boundary condition with minimal effect to the solution. To date, this technique of solution region truncation has been demonstrated for isotropic domains.

In many problems encountered in the design of integrated optical components, the materials can display strong anisotropy. For instance, the electro-optic material Lithium Niobate ($LiNbO_3$) is particularly suitable for integrated optical devices. Efficient numerical methods capable of modelling both the optical and microwave aspects of these devices form an important part of the device design process. The PML can be used to reduce the computational domain size, and hence reduce computational effort, enabling practical solution of a broader range of design problems with existing numerical techniques. Unfortunately, $LiNbO_3$ is a biaxial material, and thus the PML, in its current form, cannot be used to reduce domains involving a $LiNbO_3$ substrate.

We therefore present an anisotropic PML for the truncation of solution spaces involving biaxial materials. In order to examine the effectiveness of this technique, the finite element method is used to model reflections from a shorted parallel plate waveguide. A thin strip of biaxial PML is placed in front of the short and the resulting reflections are used to gauge the effect of the PML. The variable parameters of the PML that affect its performance are investigated.

Recent Progress on Moment Method / UTD Hybridization

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Despite the tremendous advances made in computing technology, the problem size that can be addressed with full-wave solvers has grown much more slowly than the speed of computers. The reasons are well understood; for a typical moment method radiation or scattering formulation using equivalent surface currents, the solution time grows as the sixth power of frequency (or alternately, the sixth power of the inverse of the mesh size). Various approaches to overcome this continue to receive attention ; these include hybrid methods, fast methods, and parallelization methods to permit the potential power of massively parallel systems to be harnessed. This paper addresses the first, viz. hybridization of the full-wave MoM formulation with asymptotic methods, in particular with the UTD.

Work by Jakobus and Landstorfer [?, ?] reported the hybridization of the MoM with physical optics (PO); since both the MoM and PO are current based, this permits a very elegant formulation in which the MoM or PO can be used on the same surface, with smooth blending from the MoM to the PO region. The MoM/PO hybrid is comparatively general, in that there are no specific restrictions on the geometries that can be modelled (although the heuristic improvements given in [?, ?] are only available for a small class of problems); furthermore, it does not require complex ray-tracing. (Only shadow boundaries need be determined). A powerful, general purpose MoM/PO program named FEKO has been developed which implements both a pure MoM as well as the MoM/PO hybridization; it is commercially available and there are no security restrictions on its distribution.

Although the MoM/PO hybrid greatly reduces the run-time from $O(f^6)$ to $O(f^2)$ for a problem with a small MoM part (essentially the integration of the PO currents), this can still be a significant contribution for an electromagnetically large problem. An MoM/UTD hybrid (and conceivably MoM/PO/UTD) had been presented in [?] for flat polygonal plates in the UTD region. This paper addresses extensions for curved surfaces. A problem with the UTD is that the diffraction coefficients for canonical problems are required, and the ray-tracing can become extremely complex when higher-order interactions and diffraction are taken into account, limiting the generality of the approach. However, for specific problems, this can be a very efficient formulation. We are presently implementing the necessary formulation for a cylinder with various end caps (such as flat, spherical or conical). There are many practical applications of this geometry, including the ubiquitous radio masts presently being erected for mobile telephony. Further work and examples will be presented at the symposium.

On the Use of Attachment Modes in the Analysis of Printed Antennas

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One of the most robust techniques to feed a printed antenna uses a coaxial connector whose outer conductor is soldered to the ground plane and whose center conductor is attached to the patch. This method of excitation has several advantages including better isolation between the feed circuitry and the radiating element, but is more difficult to model. Multiple probe feeds are used to achieve circular polarization and to reduce cross-polarized levels. Shorting posts are introduced to control the resonant frequency and the polarization.

Accurate and efficient numerical modeling of printed antennas featuring probe feeds and shorting posts requires the development of appropriate full-wave solutions. The full wave solution of choice for many printed antenna geometries is the Green's function/Moment Method technique. In the case of probe-fed printed antennas, one must carefully consider both the continuity and the singular nature of the current at the point where the probe is connected to the patch. These conditions can be ensured by the proper choice of a singular expansion function in the solution. This expansion function is commonly referred to as an "attachment mode." Although, different types of attachment modes have been described in the literature, we use attachment modes derived from the cavity model. Attachment modes have been obtained for rectangular, circular and annular ring patch antennas. These expansion functions have allowed us to develop a suite of accurate and efficient numerical models for the design and analysis of printed antennas. In the presentation, the approach used to develop these expansion modes and their advantages and disadvantages are discussed. Furthermore, comparisons between numerical and experimental results are presented.

Teaching Computational Methods to Undergraduates

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With increasing reliance of computational methods in all branches of advanced engineering, pressure is mounting to move the introduction of various computational methods lower in the curriculum. Traditionally, students are first introduced to a computational method when first embarking on their research project, typically a semester or two after the start of graduate work. In many cases the choice of which computational tool to choose is not well understood by the student until much later in the program, sometimes to their detriment.

At Embry-Riddle, we have attempted to prepare interested students for advanced engineering work with the introduction of an experimental *Computational Methods* class. This class, taught at the Senior level, introduces Variational Methods, the Method of Moments, Finite Difference Methods, and Finite Element Methods. The course has been highly successful in achieving its objectives, however, a number of problems have been identified and need to be resolved before the course can be considered as a standard engineering core course.

Due to the rather specialized nature of the course, enrollment remains manageable, rarely more than ten to twelve students. This is highly advantageous, since a great deal of one-on-one instruction is required at many points during the semester. The course is designed to be accessible to all engineering majors, thus mathematical maturity and programming ability were the only prerequisites. Even with the maturity and motivation of the students, however, it was found that "real" problems are typically beyond the scope of the class, since the students tend to get too caught up in the mathematics, and miss the objectives of the method being examined. This is anticipated to be a problem regardless of focus of the course taught at the undergraduate level; real problems are "real" simply because they are so difficult to formulate and solve mathematically.

The course was designed around the use of symbolic mathematical packages (such as Mathematica and Maple) and fourth-generation engineering programming environments (such as Matlab) in an effort to simplify the programming and debugging effort. To a certain extent, this strategy worked well. Matlab's interpretive environment and easy graphics output allowed in-class demonstrations of particular techniques, and lowered (but didn't eliminate) student frustration with implementing the algorithms on a computer. The primary disadvantage of Matlab (or any interpreted language) is the execution speed penalty. For the purposes of this class the penalty was insignificant due to the simplicity of the problems being solved.

Combined eigenvalue and circuit modelling of radio frequency heating systems

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Radio frequency heating systems, operating at ISM frequency bands centered at 13.56 MHz and 27.12 MHz have been used for decades for processing a variety of materials. The majority of processing installations in industry use variants of the basic class C oscillator. One of the main problems of class C operation of the circuit is the high frequency harmonics produced, due to its switching characteristics which generates a current waveform rich in harmonic content. This current flows in the tank and applicator circuits which have resonances not only close to the fundamental but also at higher frequencies depending on their actual construction and tuning.

Because these circuits are in reality resonant cavities connected together with the material load placed inside them, the finite element method can be used to solve the wave equation to determine the electric field distribution for a given design. An eigenvalue solver based on the Implicitly Restarted Arnoldi/Lanczos Methods is used to calculate the multiple resonant modes occurring in the range of interest. Once the resonant modes have been obtained an equivalent circuit model is derived using Foster's Theorem. This is then used in a circuit simulation package to simulate the actual oscillator circuit and obtain the actual power and triode operating curves for a given circuit configuration. Furthermore, the power spectrum of the system is obtained and its dependance on the various system parameters is investigated.

The main advantage of the combined eigenvalue and circuit model is the the harmonic performance of a given system design can be investigated without the need of building and testing numerous prototypes. This is very important especially with the imposition of the
EMC regulations to which the new equipement has to conform to.

Session D04
Wednesday, July 15, AM 08:40-11:20
Room 120
Numerical Techniques

Organiser : T. K. Sarkar

Chairs : Magdalena Salazar Palma, Andreas Cangellaris

Adaptive Multiscale Moment Method for Analyzing EM Scattering from perfectly conducting Objects

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It is well known that the moment method utilizing an integral equation has the limitation as it requires excessive storage and execution times for solution of even modestly large electromagnetic problems. But a conventional MoM matrix contains all the information required to solve a scattering problems. Several techniques, such as IML (Impedance Matrix Localization Method), FMM (Fast Multipole Method), MDA (Matrix Decomposition Algorithm), MLMDA (Multi-Level Matrix Decomposition Algorithm), etc., have been introduced as a fast evaluation of a matrix-vector multiplication for matrices as opposed to a conventional moment method.

Based on a special multiscale basis functions on a bounded interval which are similar to a wavelet-like basis functions, in this paper, the adpative multiscale moment method (AMMM) has been introduced in order to overcome the limitation of a conventional moment method. The impedance matrix of the conventional moment method is transformed directly into a scaled-block matrix through a special matrix multiplication. When one scale is increased, the initial guess for the solution utilized in an iterative solver at the new scale, corresponds to the solution of the original scale. The number of unknowns corresponding to the linear equations at an increasing scales can be automatically reduced by using a suitable threshold and the solution obtained from previous scales. Several examples for scattering from electrically objects illuminated by TM plane wave will be presented. Comparison will be made with respect to the numerical solution obtained by the moment method. The objective of this paper is to illustrate that a possibility exist for efficiently reducing the size of the linear equations in an automatic fashion utilizing the adaptive multiscale moment method.

Polynomial Bases and Convergence in The Method of Moments

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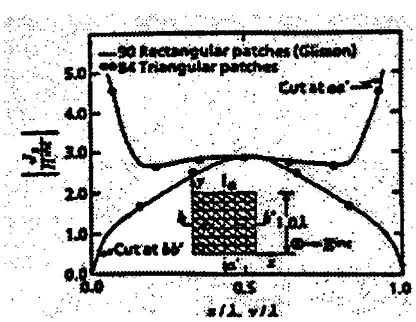
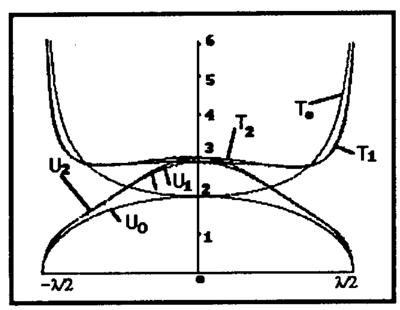
In the Method of Moments (MoM), decomposition of the unknowns can be made by two different ways. One of them is called "subsectional decomposition" and the other "entire domain decomposition". The first one is associated with the simplest basis functions whereas in the second one we have to deal with more complexes basis functions.(e.g., orthogonal and trigonometric polynomials). Experience shows that subsectional approach converges by increasing the mesh sharpness of the domain under investigation. The MoM impedance matrix size grows up and has to be entirely recalculated at each step of the convergence scheme. One drawback of this approach is to deal with a large MoM matrix and, moreover, constrains us to construct an adaptive mesh at each iteration of the scheme. It is generally used in the electromagnetic study of bodies of complex shapes. However in the special case of microwave layered printed circuits, the "entire domain approach" can be considered.

Polynomial bases are seldom used in Moment Method. This is due to the heavy numerical procedure in the evaluation of MoM matrix elements when compared to the efficient analytical developments allowed when using PWS (Piece Wise Sinusoidal) basis functions. The required CPU time is reasonable in this case but, in counterpart, it often produces a very large MoM matrix which can be difficult to store and may cause conditioning problem. Polynomials bases can circumvent this drawback by greatly improving the convergence rate of the MoM procedure. For planar circuit applications, one can take into account the transversal as well as the longitudinal edge effects in the choice of polynomials bases. In counterpart, we have to develop specifics methods for MoM matrix computation. For instance, the fast rate of convergence due to polynomial approach on the "entire domain" can be observed in the case of a $\lambda x \lambda$ metallic patch illuminated by a normal plane wave (Fig.1).



a)



b)

Fig.1: Current density distribution :
a) after Wilton et al.[1]
b) this work.

Tchebychev polynomials $T_0(x)$ and $U_0(y)$ constitute the first step of iteration (Fig 1b). Adding two polynomial bases demonstrates the accuracy and convergence of the procedure. In this paper, it is shown that this approach can be extended to dielectric and hybrid (dielectric and metallic) bodies by the use of general Meixner conditions. As a result, the procedure is applicable to more general planar structures which are used in microwave and millimeter-wave circuits.

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Passive Discretization and Reduced-Order Modeling of Distributed Electromagnetic Systems

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Rapid advances in device switching speeds, combined with the explosive growth of the wireless computing and communication market with its demands for low-voltage, low-power, tightly-integrated, mixed analog-digital circuits, have brought the need for electromagnetic computer-aided design (EM-CAD) capability to the forefront of modern integrated circuit design. Despite significant advances in electromagnetic modeling and simulation methodologies and computer tool sophistication, electromagnetic computer-aided design (EM-CAD) tools do not exhibit yet the efficiency needed for module/system design and subsequent design optimization. Except for very simple systems, the distributed linear and nonlinear electromagnetic analysis required for the design and optimization of future high-performance information processing and communication systems is hindered by the large number of degrees of freedom involved in the electromagnetic model. Thus, the direct use of time-domain nonlinear differential-equation integration, as implemented in SPICE-like simulators enhanced with transmission-line modeling or even combined with rigorous FDTD-based Maxwell's equations solvers is prohibitive for circuits of the complexity encountered in realistic integrated electronic systems.

In response to this simulation challenge, recent research efforts are focusing on the development of model order reduction techniques that allow the replacement of large linear portions of the system with a substantially smaller model that approximates sufficiently its external behavior. This way, the size of the problem left for the nonlinear simulator to solve becomes substantially smaller, and thus problems of sizes beyond the reach of conventional simulators can now be tackled. More specifically, Padé approximations to the response of electromagnetic systems are used to effect the so-called fast frequency sweep, where the system response over a broad range of frequencies is obtained at approximately the cost of factoring the approximating matrix at only a few frequency points. In addition to rapid broadband calculation of the frequency response of an individual electromagnetic component or a specific functional block, the development of macromodels of electromagnetic multiports is essential for design-driven simulation of large electromagnetic systems. When macromodels for multiports are connected together, it is important to keep in mind the fact that interconnections of stable systems may not necessarily result in stable systems; however, interconnections of passive circuits always result in systems that are passive and, hence, (asymptotically) stable. This, then, implies that it is not enough for an electromagnetic macromodel to be stable. What matters, when this macromodel is to be connected with other functional blocks, is for the macromodel to be passive.

In this paper, recent advances in electromagnetic model order reduction are reviewed. In addition, a specific methodology is introduced for passive model order reduction of semi-discrete electromagnetic systems obtained from the spatial discretization of the hyperbolic system of Maxwell's equations. It is shown how the properties of the original semi-discrete system impact the passivity of the developed reduced-order model, and specific criteria for developing passive reduced-order models are established. The mathematical development is supported by numerical results from the reduced-order modeling of microwave filters and antennas.

Radiation/Scattering from 3D Conducting/Dielectric Structures Utilizing the Finite Element Method

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The Finite Element Method is utilized for the analysis of radiation and scattering from three dimensional conducting and dielectric structures. The finite element method is set up for the solution of the differential form of Maxwell's equations in a three dimensional system. A radiation condition is utilized to terminate the finite element mesh. The termination criteria is based on the use of the Green's function The advantage of using this approach is that the FEM matrix is still sparse and an iterative method is utilized to generate the solution. In addition the computational technique is very efficient as only two layers of finite element mesh is required to terminate the mesh. However, the method used here is not the usual hybrid method using the integral equation approach and the finite element method. Actually, the method starts by assuming arbitrary values of the field at the terminating boundary applied as an essential condition. Then FEM is applied to solve for the unknown. From the field solutions, the surface currents are determined on the surface of the conductor or the dielectric or on an artificial surface. Once the equivalent surface currents are determined, the fields at the outer boundary can be computed. From the fields on the outer boundary, the Maxwell's equations are solved inside the structure and the iteration continues till a convergent solution for the fields are obtained. The method is guaranteed to converge under all conditions.

The basis functions used in the solution of the three dimensional radiation-scattering problems is based on the use of curl conforming elements (of the Nedelec type) as the basis functions does produce spurious solutions. However, the spurious solutions appear as the eigen-vectors corresponding to the zero eigenvalue. Hence, even though, the spurious solutions appear in the procedure they do not create any problems as they can be easily discriminated from the physical solutions. The talk will present numerical results generated by this procedure and compare its accuracy with the solutions generated by the method of moments for various radiation/scattering problems.

On the Condition Number of Impedance Matrix by Orthogonal Wavelet Transformation

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There have been many papers of using wavelet techniques to solve scattering problems. The dense impedance matrix resulting from discretizing the integral equation by the conventional moment method will then become a sparse matrix by use of the wavelet transformation. And many researchers thought that it will be easy to find out the solution of the sparse matrix equation. However, when the condition number of the matrix is large, it will be a significant barrier to find the accurate solution of the matrix equation. Although many papers have been written for solving the integral equation by the use of wavelet transformation, they seldom discuss the condition number of the coefficient matrix. In fact, EFIE results in a mathematically ill-posed problem. The condition number of the resulting moment matrix increases as more expansion functions are used per wavelength.

In this paper, we discuss how to construct the discrete wavelet transformation from designing a FIR (finite impulse response) filter, and discuss the compression rate of the matrix by use of the derived wavelet transformation. The computational time in the computation of the wavelet transformation in the compression of a matrix is investigated. Several numerical examples of computing the condition number and solution of the matrix equations are presented. From the numerical results, it is seen that the condition number of the impedance matrix transformed by orthogonal wavelet transformation and after filtering out the relatively smaller elements through a suitable threshold changes the condition number. Utilizing a higher order filter does not necessarily produce a larger sparsity of the matrix. There are no clear relations between the changes of condition numbers of the impedance matrix and the order of the filters and the compression rate of the impedance matrix. Therefore, the advantage of using the orthogonal wavelet transformation for solving the original ill-posed discretized EFIE problem is questionable.

Low Frequency Electromagnetic Scattering from Conducting Structures Utilizing Triangular Patch Modelling

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Conventional integral equations formulations has problems at very low frequencies. This is because the major contribution to the radiated far fields comes from the magnetic vector potential whose contribution decreases linearly with frequency. The other contribution to the electric field which is due to the scalar electric potential increases with frequency with an inverse law. However, the scalar electric potential does not contribute to the radiated far fields yet they are significantly larger in magnitude than the contribution from the magnetic vector potential. This creates a significant numerical problem at low frequencies. also the Green,s function needs to be computed very accurately over a triangular patch particularly when the dimensions are small. One way of getting around the numerical instability problem is to expand the current into curl-free and divergence-free basis functions as has been published by Rao et al. The advantage of doing that is to break down the basis functions into two parts. The first part which is curl-free contributes to the computation of the magnetic vector potential whereas the contribution of the divergence-free part results in the evaluation of the scalar electric potential. However, in spite of the separation , in order to increase the numerical accuracy it is necessary to integrate over the triangular patch with a very high degree of accuracy for electrically small structures. This can efficiently be accomplished by expanding the Green's function into a series where the integration for the singular term is done analytically and a recursive relationship is developed for the other terms. The talk will summarize the developments and will illustrate the methodology.

Fourth Order Accurate Compact Implicit Method for the Maxwell Equation

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We consider a fourth order accurate compact scheme for the numerical soluton of the Maxwell equation. We use the same mesh stencil as used in the standard Yee scheme. In particular extra information over a wider stencil is not required. This has several advanteges. First, it is relatively easy to modify an existing code based on the Yee algorithmto make it fourth order accurate. Second, a staggered mesh, without additional mesh location, makes the boundary treatment easier since some of the quantities are located inside the domain rather than on the boundary. Finally, a staggered grid system gives a lower error than a similar non-staggered system.

We base this scheme on the following relation :

$$\begin{bmatrix} 26 & -5 & 4 & -1 & 0 & . & 0 \\ 1 & 22 & 1 & 0 & . & . & 0 \\ 0 & 1 & 22 & 1 & 0 & . & 0 \\ . & . & . & . & . & . & . \\ 0 & . & . & 1 & 22 & 1 & 0 \\ 0 & . & . & 0 & 1 & 22 & 1 \\ 0 & . & . & -1 & 4 & -5 & 22 \end{bmatrix} \frac{d}{dx} \begin{bmatrix} U^{1/2} \\ U^{3/2} \\ . \\ . \\ . \\ U^{(2p-3)/2} \\ U^{(2p-1)/2} \end{bmatrix} = \frac{24}{\Delta x} \left(\begin{bmatrix} U^{1} \\ U^{2} \\ . \\ . \\ . \\ U^{p-1} \\ U^{p} \end{bmatrix} - \begin{bmatrix} U^{0} \\ U^{1} \\ . \\ . \\ . \\ U^{p-2} \\ U^{p-1} \end{bmatrix} \right)$$

The error in forth order scheme decreases significantly in comparison with Yee's second order scheme. This allows us to use a much coarser mesh, and therefore use less computer time.

We present numerical results not only for simple cases as waveguides and sources in free space, but also for dielectrics. We smooth the dielectric coefficients with a fourth order implicit interpolation. This interpolation reduces the error, both in the Yee scheme and the fourth order scheme. In the new scheme the error decreases dramatically. This enables us to use a coarser mesh and less computer time in comparison with Yee's scheme.

We conclude that the fourth order scheme is more accurate and efficient than Yee's scheme. Yee's scheme requires a mesh about 8 times finer in each direction and hence requires much more computer time for the same accuracy.

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+Amir Yefet is a doctoral student there.

Session E04
Wednesday, July 15, AM 08:40-10:00
Room K
Coplanar Techniques

Organiser : G. Alquié

Chair : G. Alquié

A Simple Analytical Model for the Coplanar Waveguide Open-End Discontinuity

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A simple analytical model for the coplanar waveguide (CPW) open-end discontinuity, having central conductor width w and slot width s, is presented. It uses a simple equivalent capacitance C_{open} that is described by explicit functions of the gap width g between the end of the central conductor and the end of the ground planes, permittivity of the substrate and line physical dimensions. Finite Difference or Finite Element techniques have been successively used to characterize the CPW open-end discontinuity, but these techniques are not adapted to be used in CAD programs. Firstly, Beilenhoff et al. [1] have given a very simple approximation for C_{open} associated with the fringing field in the case of open-end discontinuities having a wide gap g. On the other hand, an analytical formula for C_{open} has been presented for smaller values of g (narrow slot approximation) that is based on the determination of the static potential in the slot region [2]. In our paper, only one simple formula for the calculation of C_{open} in the whole range of gap width values, is presented. It is given by the approximate expression determined from Eqn. 1.

$$C_{open} = \frac{4\varepsilon_0}{\pi}\varepsilon_{re}(w+s)\ln\left[\frac{\sqrt{1+(\alpha\delta\gamma)^2}+1}{\delta\gamma}\right] \text{ and } \alpha = \exp\left(\frac{\pi}{\varepsilon_0+\varepsilon_0\varepsilon_r}\cdot C^0_{open}\right),\ \gamma = g/(w+\sigma s)$$

where $C^0_{open} = \varepsilon_0\varepsilon_{re}\dfrac{K(k)}{K'(k)}$ and $\delta=31.8$, $\sigma=1.6\times10^{-2}$

The precision of the proposed model is demonstrated by comparing results for test cases using this model to those obtained either experimentally or using rigorous 3D finite difference analysis [3]. A very good agreement is reported for typical CPW open-end discontinuities that are deposited on GaAs substrate. Our model has the advantage of giving C_{open} in terms of the substrate permittivity εr so it is not limited for lines deposited on a particular substrate. Furthermore, this simple model that is valid for any given line geometry, represents a very important tool that can be easily introduced in CAD programs.

References

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The Uniplar Technology, a very Convenient Way to Built High Performance Passive Microwave Devices

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Microstrip transmission line has been predominant by use in microwave integrated circuits. Nearly all well known passive microwave devices can be built in microstrip (eg couplers, filters, etc). By contrast only a few investigations were made of the capability to build such devices in uniplanar technology. However, the recent developments of this technology has offered microwave designers more facility and flexibility in microwave and millimeter circuit integration. The association of coplanar and slotline and the use of both parallel and series passive and active devices considerably facilitate circuit technological implementation. Among these advantages, the inherent decoupling of adjacent lines offers high flexibility in circuit design and miniaturisation without sacrifing the performances. The objective of this paper is to show that the use of uniplanal technology led to new developments in the design of original passive circuits and multifunction devices.

For instance, we present the design of new types of series resonators and their implementation in high performance low pass and band pass filters.
Theoretical modelisation of uniplanar technololy is discussed to define a convenient design procedure for centimeter and millimeter wave circuits. For each basis device, an equivalent circuit is proposed and experimentally validated up to 50 GHZ.

Association of these resonators is also discussed to demonstrate the interest of uniplanar technology to design miniaturized and high performances circuits.
Moreover we show how the use of uniplanar allows to design low cost convenient multifunction devices.

Finally, to develop reliable process on one hand and to introduce more degrees of freedom for the designer on the other hand, we propose the development of multilayer unilplanar technology. Dielectric bridges are theoritically and experimentally studied, their influence is directly taken into account in the design of passive circuits. The interest of such a technology, now developed in our labolatory, is illustrated on several theoretical and experimental results obtained on devices such as transitions or filters.

Simple Manufacturable Rectangular Waveguide to Coplanar Line Transitions

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Waveguides (WG) are often utilised for antenna or filter design. This paper presents a new, easy to build transition from a coplanar line to a WG, which is often needed to embed WGs into MMIC designs or vice versa. In contrast to the well known E-plane probe-transitions [1] and ridged waveguide-transitions [2], the proposed waveguide transitions do not require modifications of the waveguide and the planar design. One transition was optimised for a broadband transmission and the other was optimised for low radiation leakage. The design was done utilising a field simulator based on the Finite Difference Time Domain Method (FDTD) [3]. Measurements for verification are also presented.

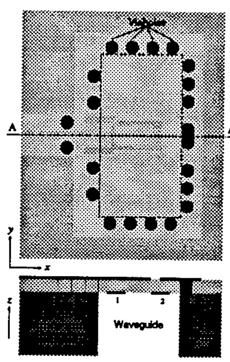

Fig. 1: Top- and sideview of the waveguide-transition.

The transition as shown in Fig. 1 consists of a doublesided structured substrate placed on top of the waveguide. On top of the substrate the structure on the left side can be interpreted as a coplanar to microstrip transition concentrating the electromagnetic field between the stripline and the backside metallization. This causes the excitation of the metal strip 1 on the backside. The metal strip 2 is coupled capacitively to the wided microstrip line. So the two metal strips are excited with a phase displacement that yields a strong electrical field in x-direction between the metal stripes as well as in the slots between the metal stripes and the waveguide. This yields that mainly the TE_{10} mode is excited as wanted.In the first design the structure on the top and the patch dimensions were optimised to achieve a broadband transmission.

To verify this design, a test structure has been built, and measured. It consists of two coplanar-waveguide transitions to allow the use of waveguide NWA for measurement. The measurements compared with simulation results are shown in Fig.4. Fig.5 shows the simulation results for the second structure, optimised for low radiation leakage.

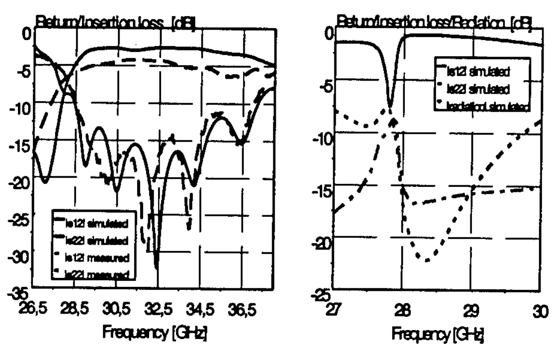

Fig. 4,5:Scattering parameters of the two transitions.

It can be seen that the first transition achieves a bandwidth of 5 GHz at a minimum return loss of 15 dB. The insertion loss of about 4 dB for two transitions is an indication for a slight radiation leakage. The second transition for an antenna feed at 28.5 GHz achieves a bandwidth of 1GHz for return loss of 15 dB as well as an insertion loss of 0.5 dB for two transitions. The minimum radiation suppression calculated from the insertion loss is better than 15 dB. The comparison to measurements of a test structure will be supplied with the final paper.

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Inductance Computation for CPW Discontinuities with Finite Metallization Thickness by Hybrid Finite Element Method

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The uni-planar transmission line structure based on the coplanar waveguide (CPW) has been developed as a circuit element for monolithic microwave integrated circuits (MMIC). Accurate analysis and characterization of CPW discontinuity is important in designing the MMIC. As the line size in the metallization plane shrinks, the influence of the metallization thickness becomes not negligible and should be taken into account.

In this paper, a variational formula in terms of the magnetic flux density is proposed in the inductance computations for CPW structures with finite metallization thickness. From the theory of guided wave, the total stored magnetic energy can be derived and expressed in terms of the magnetic flux density

$$
\begin{aligned}
Wm = & \frac{1}{2}\int_{\Gamma^u}\int_{\Gamma^u} G^u(\bar{\rho};\bar{\rho}')B_z(\bar{\rho},z=t)B_z(\bar{\rho}',z'=t)\,d\Gamma d\Gamma' \\
& +\frac{1}{2}\int_{\Gamma^l}\int_{\Gamma^l} G^l(\bar{\rho};\bar{\rho}')B_z(\bar{\rho},z=0)B_z(\bar{\rho}',z'=0)\,d\Gamma d\Gamma' \\
& +\frac{1}{2}\int_{\Omega}\frac{1}{\mu_0}\bar{B}\cdot\bar{B}\;d\Omega
\end{aligned}
$$

where Γ^u and Γ^l denote the planes z = t and z = 0, respectively. The Green's function for the CPW structure is $G^u(r) = G^l(r) = \frac{1}{2\pi\mu_0 r}$ where $r \equiv |\bar{r}-\bar{r}'|$ Introducing Lagrange multipliers, the variational equation can be solved by the hybrid finite element method.

Numerical results for the equivalent short end inductance will be presented and compared with published data [1]. In the case of thinckness $t=3\mu m$ and s/d=0.3, the incremental inductance due to metallization thickness is about 14%. It is quite noticeable and should be considered in typical MMIC design. When the thickness is small, the variational equation can be reduced to a perturbation formula involving the normal magnetic flux density which is available in the inductance computation for CPW with zero thickness. Then, the errors due to this approximation are investigated by comparing the results with hose by the more accurate bybrid finite element method. Finally, some numerical results for extensive discontinuities will be presented by employing the perturbation formula.

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Session E05
Wednesday, July 15, AM 10:20-11:20
Room K
Developments in the Area of the Calculations of Guided Waves and Propagation

Organiser : A. Beyer

Chairs : A. Beyer, V. Fouad Hanna

Object-Oriented Non-Linear Analysis in the Frequency-Domain for Advanced Non-Linear Device Modelling

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Non-linear device models are mostly defined in the time-domain to be compatible with the harmonic-balance analysis, which is the dominant non-linear analysis tool in commercial CAD programs. However, those non-linear models are mainly based on frequency-domain S-parameter measurements. Furthermore, non-linear circuit analysis in the frequency-domain can be favourable, especially to avoid convergence problems in the case of multi-tone excitations. Therefore, we have developed a novel simulation tool.

The simulation tool has been conceived as an object-oriented environment composed of a simulation engine, which performs circuit simulation purely in the frequency-domain, and a model library, which allows that many different non-linear modelling approaches can be attached to the same engine. The simulation engine uses utility modules to perform such basic operations as parsing of the input file, solving the non-linear system, performing algebraical computations, etc. This environment enables to perform simulations of circuits with arbitrary topology. The circuits are analysed at run-time and changes to their topology does not require recompilation of the source code. The simulation environment has been successfully verified by comparing DC and harmonic distortion simulations on a sample transistor to results obtained by Libra.

The novel feature of this simulation engine is that it has been conceived, from the beginning on, as numerically efficient universal tool. Its universality and versatility lies in the fact that it makes use of a model library which is composed of many different non-linear modelling approaches. After a brief discussion of non-linear models based on DC and vectorial linear measurements [1], we will mainly evaluate a new analytical procedure in the frequency domain to extract the model of non-linear components, such as diodes, MESFETs, HEMTs and bipolar transistors, directly from vectorial large-signal measurements [2]. Since these measurements contain both the amplitude and phase information of the harmonics of all the travelling voltage waves, it is theoretically possible to extract the device's state-functions from these measurements. The requirement to distinguish the current and the charge sources is that different measurements at constant spectra of the terminal voltages are needed. The consequence is that it is difficult to implement this analytical method in practice, which implies that numerical approaches in the frequency domain should be considered.

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Using a Structure Description Language for Electromagnetic Field Simulation

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In the last years the importance of the numerical simulation of electromagnetic fields in millimetre and microwave devices has steadily grown. The simulated structure and the simulation parameters can either be specified in the software code, which makes recompilation necessary after every change of one of those, or in an input file. There are various ways to generate such an input file, e.g. by drawing the simulation geometry with a simple vector-oriented drawing program (like xfig), or by entering the geometry specification directly in an input file. The first method has some advantages, but has severe disadvantages in the three-dimensional case, unless a commercial 3D-CAD tool is used. In the latter case the CAD tool must first be bought and secondly a filter must be written for analysing the output format of the CAD programme. In the case of a direct input parameter file the handling gets difficult for all others than the programmers of the simulator.

The use of additional programmes can be circumvented, if an easy way is found to specify the structure directly. One way of doing this, is explained in this paper. A simple structure description language (SDL) is implemented to specify both the geometry of the simulated structure and the simulation parameters [1,2]. The fact that this description language can be used both in the two- and three dimensional case makes it a generally applicable field simulation input tool. The description language is able to handle macros, even if macros are specified inside macros. The macros can also handle parameter lists. Thus, a library of structure parts used often, e.g. a three dimensional rectangular conductor, can be written to handle larger complicated structures.

Although this SDL was implemented for the Transmission Line Matrix (TLM) simulation method, it is generally applicable to all related simulators which solve similar problems. The language supports all basic geometrical structures and provides all standard elements of programming languages like conditional execution, loops, variables and output onto a file or the screen. Thus, the SDL presented in this paper is a simple tool to generate input of electromagnetic field simulators. When used with the SDL presented above, a field simulator can easily be handled by anybody, who has some basic knowledge of microwave engineering or electromagnetic field theory.

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On the Generalized Theory of Waveguide Mode Excitation

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1) The orthonormal basis of waveguide eigenmodes can be used to solve waveguide excitation problems [1], [2]. A full spectrum of waveguides contains propagating and non-propagating modes. It is known that every evanescent mode and every complex mode in a closed waveguide do not transfer an active power flow. Transmission of the electromagnetic energy is possible only by pairs of conjugate evanescent or complex modes and may be realized only in finite-length waveguides. It means that the theory of a full-mode-spectrum excitation in closed waveguides may be applicable only for regions with the finite length.

2) To solve an excitation problem in waveguides based on complex media the so-called spectral method may be successfully used. An analysis of waveguide problems based on a solution of full vector-form equations shows that a special attention has to be paid to the role of the longitudinal components of the excitation (electric and magnetic) currents [1], [4]. In an analysis of waveguide mode interactions, special consideration has to be given to the so-called induced polarization effects caused by discontinuities of longitudinal polarization currents [5], [6].

3) In different types of waveguides described in the literature, external (given) currents and charges are considered as sources of mode excitation. For some waveguide problems concerning excitation of quasistatic modes in ferromagnetic and piezoelectric waveguides, another type of excitation may be, however, considered. There is mode excitation due to the external (given) electric and magnetic fields [7], [8].

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Session E06
Wednesday, July 15, AM 11:20-13:00
Room K
Packaging

Organiser : O. Picon
Chair : O. Picon

Tape Automated Bonding Package for High Speed IC's

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Computers incorporate more powerful high speed integrated communication circuits (1-4 Gbps) in order to increase transfer speed. High speed integrated communications circuits use technologies with small voltage swing (~ 500 mV) and require low attenuation (~ 10 %).

At the board level, packaging has to be compact, with the smallest possible discontinuities in the controlled impedance transmission lines and low attenuation. For the electrical design of these associated packages, we must take into account propagation aspects: signal reflection, cross-talk and losses. Controlled impedance is obtained through modeling by selecting optimum physical and geometrical transmission line structures and by optimizing the material and geometrical aspects of the connection.

In this paper, we describe

- The electrical design considerations (modeling, simulation) to ensure 50 Ω controlled impedance, low cross-talk noises.
- The Tape Automated Bonding construction on the high speed silicon chip
- Then electrical performance of the silicon/TAB construction for high speed BiCMOS integrated serial link (3 Gbps).

Special acknowledgments to Dassault Electronique partner who has strongly contributed to this development supported by the French Ministry of Defense (DGA).

Quad Flat Package Assembly Performances on Radio Frequency Range

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A general methodology for Quad Flat Packages electrical modeling is presented ; the influence of different parts on dynamic performances is pointed out. To illustrate the use of our models in a CAD application, an assembly including the QFP-24 package and a high frequency SPDT switch has been simulated. Results are discussed in terms of isolation and insertion losses up to 4GHz ; effects of connection paths to ground are emphasized. This general scheme has been successfully applied on other kind of packages like S08 for example [1-2] commonly used on RF public applications.

Analyzed structure

The typical top view of the QFP-24 package is given in figure 1. In order to analyze this 3D configuration, each lead is splitted on single 2D structures ; the electrical model of these later is obtained using an Integral Equations and Moments Method Techniques.

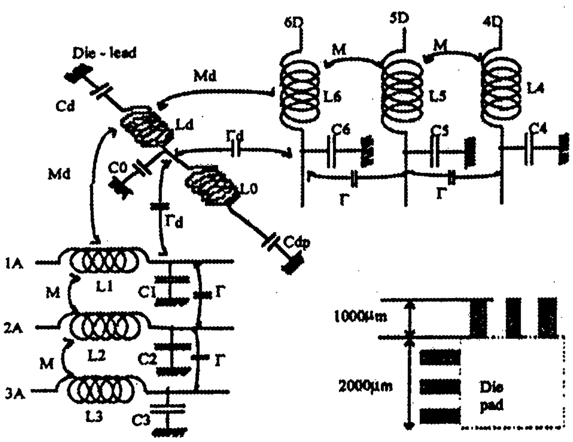

Fig 1: Simplified equivalent circuit of fi package with coupling elements

So, propagation characteristics are calculated for different parts of the package in terms of L and C matrices defined for multicondor transmision lines. From these matrices, a global reduced equivalent network of a 1/4th package is proposed. In order to analyze the dynamic performance of the QFP, SPDT switch is assembled with the QFP.

Results

Our simulations showed that the isolation losses (transmission through path off) are strongly dpendent on the number of pins connected to ground (18dB, 23dB and 27dB respectively for 2, 4 and 8 leads connected to ground at 4GHz). Using the package model, an optimization of the layout of assembly is performes and the frequency limitation of the package due to this common mode coupling effect is pointed out.

This methodology is applicable to any plastic or ceramic package and asemblies operating into radio-frequency range (lumped concept). For higher frequencies (up to 10 GHz or higher), distributed concept must be used and specific microwave packages are commonly designed by qtandard electromagnetic technique based on Sparameters modeling.

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New Results on Electromagnetic Field Coupling for MM-Wave Interconnects

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With increasing frequency, interconnects to and between MMICs and feed-throughs into hermetically sealed packages are becoming more and more difficult due to the discontinuities associated with bond wires and "thick" dielectric walls of the package. As a possible solution, electromagnetic (EM) field coupling for interconnects and package feed-through structures for mm-wave MMICs has been successfully demonstrated in /1/. This contribution will report on one hand, on new result concerning a combination of on-wafer testing and interconnects using EM field coupling techniques, and on the other hand, on a new solution for a package feed-through configuration based on low temperature cofired ceramic (LTCC) carrier substrates.

For a cost effective production of mm-wave front-ends, MMICs have to be tested on-wafer. For microstrip circuits, this typically requires via holes placed besides input and output lines, resulting, however, in some problems with compensation techniques for bond /3/ as well as for EM-coupled interconnect methods. Therefore, a technique to test circuits on-wafer without vias was proposed recently /2/. This now is combined with the EM-coupled interconnects for mm-wave microstrip MMICs as shown in Fig.1. Results of the transition from the prober tips to the microstrip line are plotted in Fig. 2.

Using LTCC substrates, the transition into and out of a package can be performed in a buried layer of the substrate. One solution to couple a microstrip line to a buried triplate is based on EM slot coupling as shown in Fig. 3. Theoretical performance of such a transition is displayed in Fig. 4.

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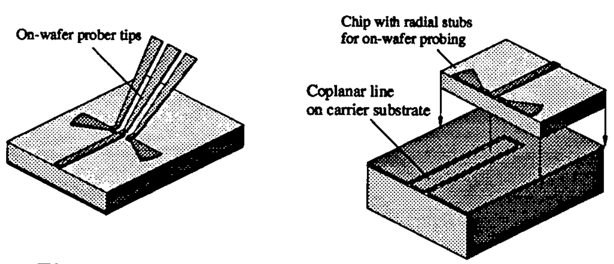

Fig. 1 : Principle of EM-coupled on-wafer testing and interconnect

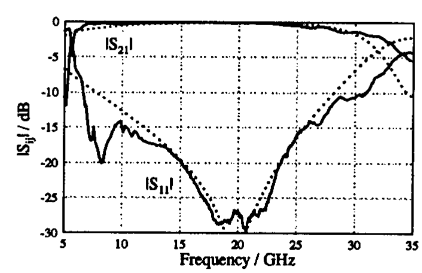

Fig. 2 : Theoretical and experimental results of a transition from on-wafer prober to microstrip line according to Fig. 1.

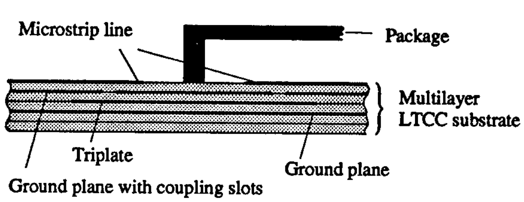

Fig. 3 : Microstrip-triplate feed-through transition

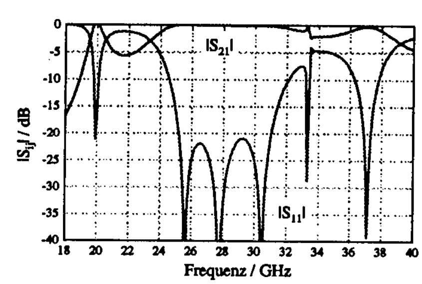

Fig. 4 : Computed performance of transition

Electromagnetic Modelisation of Millimeter Wave Interconnections

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In microwave integrated systems, as the Monolithic Microwave Integrated Circuit (M.M.I.C.) size decreases, the number of chip interconnections on the motherboard increases. In the same time, there is an intense effort to reduce the cost of these microwave systems. So, optimization of microwave circuits and M.M.I.C.'s interconnections becomes a major challenge.

The Finite Difference Time Domain (F.D.T.D) method has been first applied for the evaluation of frequency dependent parameters of discontinuities like wire bounding, tape air bounding, bump.

High frequency operation is the cause of parasistic electromagnetic phenomena such as radiation, surface losses, coupling. The F.D.T.D. method is a suitable method because it takes into account all these effects and there is no assumption concerning the environment. The theoretical tool has been validated by experimental results up to 75 Gigahertz.

This numerical method has been later applied to more complex discontinuities : interconnections between a chip and the transmission lines printed on the motherboard substrate.

Different configurations of interconnection have been evaluated. In particular, the 'Flip-Ribbon' interconnection developped by THOMSON-CSF has been considered. It consists of presenting the active face of the chip in front of the receiving lines and of making transition via rectangular strips. The characterization shows the existence of chip resonances occuring in the millimeter-wave range and some solutions are proposed to reduce these parasistic effects.

Equivalent Circuit of Flip-Chip Interconnect

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The purpose of this study is to model Flip-Chip interconnect of a coplanar line and a GaAs chip, with the help of the Transverse Resonance method and a variationnal approach using extended test functions. The use of this method allows reduced size matrix. The saving of storage and computation time compared with any method requiring the meshing of the structure is important. This work is mainly concerned with the analysis and characterization of the Flip-Chip discontinuities with the objective to develop an equivalent circuit model of the transition.

The Flip-Chip transition is made up of three different parts. An input coplanar wave guide, the region of the bumps which corresponds to the flow of signal on the MMIC chip and the last part is the MMIC chip. The Flip-Chip transition can be reduced to the study of the cross section of each part, called all along this paper, CPW, structure 2 with bumps and GaAs chip.

The equivalent circuit model of the overall flip-chip transition is given by the cascading of three two-ports networks, the first one corresponds to the discontinuity between the CPW and the structure 2, a length of line which corresponds to the diameter of the bumps, and the third two-ports network corresponds to the discontinuity between the structure 2 and the GaAs chip.

We have made a study of the parameters of diffraction of a Flip-Chip transition. We'll compare the results between an integral method, the TLM 3D [1], and TEM method where scattering parameters are deduced from the characteristic impedance of CPW and GaAs chip. From this study, the results obtained by an integral method are more realistic than a TEM model. We compare scattering parameters between the integral method and TLM 3D for adjacent structures. We can note that the Flip-Chip technology permits to have a very low S_{11}. The study of the influence of the height of the bumps on the S_{11} parameter cause a degradation of the transmission, so, to optimize the transition, it will be important to have small height of bumps.

The use of extended test functions gives matrix with smaller size, in consequence, this method is faster than a FT-DT method [1-3]. A general circuit model with five elements permits to obtain a simple model with only two elements. Results of scattering parameters permit to see that the Flip-Chip technology gives a very low S_{11}. The equivalent circuit which is given in this study can be used in commercial simulators to predict MMIC performances.

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Session F04
Wednesday, July 15, AM 08:40-12:00
Room B/C
Array Antennas
Chairs : G. Biffi Gentili, L. Beaulieu

A Serially Fed Dual-Polarized Array for Base-Station Applications

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The last few years have seen an increasing interest in using polarization diversity at cellular telephone and personal communication network base stations.

A new serially fed dual-polarized array based on a cross-shaped slot-coupled patch, is here proposed and investigated.

The array design technique and performances are derived from the analysis of the basic four-port cross-shaped patch (Fig 1). This basic antenna supports two orthogonal resonant modes. Each mode is excited through a couple of orthogonal slots etched in the ground plane separating the radiating structure from the microstrip feeding network.

The particular feeding structure chosen allows to obtain a remarkable operational flexibility while maintaining the simplicity and compactness required for the reduction of radiation and conductor losses. A dual ±45° linear slanted polarization can be easily achieved by using a simple switch to drive the proper fed-line. Moreover the polarization properties of the antenna can be easily modified to achieve vertical, horizontal or circular polarization by properly setting the amplitude and/or phase at the two inputs of the array.

The design of the series-fed sub-array is carried out by employing a method based on the image parameter approach commonly used in analyzing periodical structures and filters. This procedure greatly facilitates the synthesis of either traveling-wave type or resonant type arrays and allows a good physical insight of the antenna behavior through the frequency dependence of the real (a) and imaginary (b) part of the image propagation factor (g).

A prototype of the basic antenna has been fabricated and tested in order to validate the full-wave simulations. The design and simulation of a 2.45 GHz 5-elements resonant sub-array has been finally carried out in order to demonstrate the correctness of the proposed design procedure.

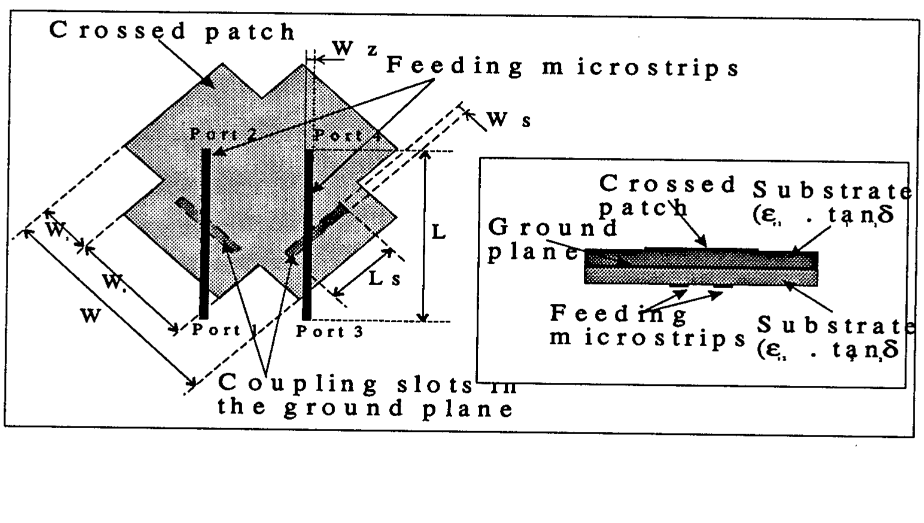

Fig.1)

"Aperture Reduction" : Using Aperture Field Eigenmodes to Analyze Finite Arrays of Aperture Coupled Antennas

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For microstrip antennas, the common way of coupling electromagnetic energy to a radiating patch with an aperture is to use a long narrow "slot". In this case a single sinusoïdal basisfunction for the dominant field component is suffficient to describe the aperture field. However, when the aperture has a general shape (special aperture shapes are used to increase feed line to path coupling, to enhance impedance matching and bandwidth) or when the radiator itself is a special shape aperture, a complete subsectional expansion of the aperture field taking into account all (tangential) field components can be required. The large number of unknowns involved with an accurate subsectional description of such an aperture field makes a mutual coupling analysis in large finite arrays infeasible.

A new technique is proposed to generate entire domain expansion functions for an arbitrarily shaped aperture, taking into account all (tangential) field components over the aperture. The entire domain expansion functions are calculated numerically as eigenmode magnetic current distributions of the aperture. They are "special" in the sense that they include the effect of passive conductors and sources located in the vicinity of the aperture. This influence yields eigenmodes that are tailored to describe the true aperture field. In general however, a number of eigenmodes equal to the number of subsectional expansion functions is obtained. To obtain a significant reduction in the number of unknowns, only a limited number of these eigenmodes will be used. A criterion was devised to select the modes that are "best" suited for expanding the aperture field. The criterion makes an estimate of the contribution of each mode in the real power transport throught the aperture. Modes contributing heavily in the real power flow are likely to be "best" modes, since eigenmodes that carry mainly reactive power are evanescent fields whose attenuation inhibits them from contributing in the overall coupling phenomenon through the aperture. Investigation has shown that a limited number of eigenmodes can be used instead of a complete subsectional expansion of the aperture field.

These eigenmodes can then be used to perform the mutual coupling analysis in finite arrays at a strongly reduced computational effort. Efficient routines for determining eigenvectors are widely available, so that the time gain in the array calculation far outweighs the time required to compute the eigenvectors, select the "best" ones, and to convert to an entire domain description of the aperture field. Comparison of full subsectional calculations with the new method show the validity and advantages of this new procedure.

Multifrequency conformal printed array

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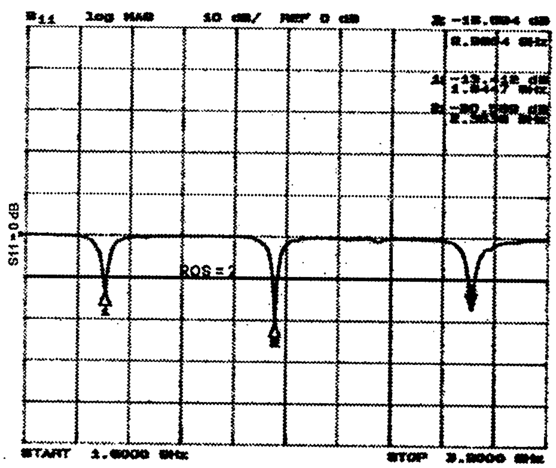
Gathering multiple frequencies on the same antenna can be obtained by a multifrequency element associated in array.

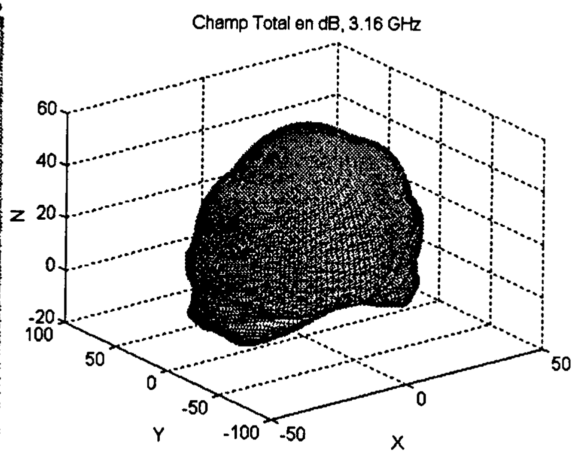
This paper deals with an original geometry of printed antenna that operates at three or four frequencies of the same octave. The feed line is a stripline to avoid parasitic front and back radiation. The geometry is based on overlapped parts slot coupled and parameters are set for the element to work at chosen frequencies.

The association in array implies the frequency ratio to be < 2, for the coupling between elements at the lower frequencies not to be too important.

A fourth power divider has been designed, matching over 50% bandwidth and multifrequency array of printed elements has been obtained.

Then, this array has been bent and conformed on a cylindrical surface. The complex radiating pattern is calculated with CONFORM that calculates radiating patterns of conformal arrays, and measured. Results presented show a good agreement.





Ring Array Sythesis Using Efficients Techniques of Sampling Circular Aperture Distributions

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The sampling of circular apertures with continuous distributions using discrete feeding on the form of ring arrays is considered in this paper. The generally complicated continuous aperture-feeding problem is thus transformed to simply determining the array excitation coefficients. Most of previous sampling techniques were based on discretizing apertures into rectangular grids (cells). The feeding coefficients of the corresponding array element is either taken as the actual value of the corresponding continuous aperture feeding (conventional sampling (CS)) or as the average value among the cell area (integrated sampling (IS)). We have extended this technique to synthesize concentric ring arrays with special geometry with either CS or IS feeding. The rings are discretized into radial sectors each with either equal on or unequal areas. The proposed techniques have some advantages over previously used ones such as the simplicity of calculating the feeding coefficients and using less number of array elements, in general. Numerical results demonstrate that the proposed aperture sampling techniques give exalted approximations of the required far field patterns for many types of aperture feeding including uniform, linear taper, parabolic taper and Taylor distributions. A detailed comparative study with other techniques is also presented. As example of the results, two of our techniques using only 256 elements are shown to give better results than those obtained by a rectangular grid array of 300 elements, for -30 Taylor pattern.

Analysis of an Active Focal Array Fed Reflector (FAFR). Comparison with an Active Direct Radiating Array (DRA)

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An active Focal Array Fed Reflector (FAFR) was analyzed, developed and tested at ALCATEL. It consists of a multiple spots active array located around a parabolic reflector focus. A limited number of elements contribute to each spot, depending on its pointing. A beam forming network realizes the feeding law for each spot, which points accurately the beam and compensates for the phase aberration of the optic.
Measured performances will be presented. A special attention will be paid to the achievement of low level sidelobes.

The FAFR will be compared to an active Direct Radiating Array (DRA) in terms of architecture complexity (number of controls, of amplifiers), in terms of electrical performances (G/T, sidelobes, spot reconfigurability, nulling capability, linearity), in terms of mechanical characteristics (mass, implementation on spacecraft), and in terms of flexibility (sensitivity to failures, sharing of power).

Active Broadband Array Using a Surface Mounted Monopole Concept

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The communications systems are bringing new challenges in antenna design. The antenna has to be a part of the system and therefore need to be as compact, cheap and simple as possible. Moreover the growing interest in Multi-mode communication systems asks the merging of several frequency bands in the same equipment. It then leads the antenna to be treated either in a wideband frequency range [1,2] or in a multi frequencies option [3].

In the present work, the basic antenna structure is a broadband monopole antenna which is coupled to a microstrip line. This concept has been already tested successfully to achieve for single monopole wide band and omnidirectionnal pattern [4]. Moreover it is cheaper since it doesn't require connector going through a ground plane like in [1]. We called it the surface mounted monopole, since this basic structure could be embedded in transparent material and drop on the feeding line as classical component.

Another original improvement for the single monopole is to propose a cross monopole configuration to improve the gain and radiation pattern.

This paper proposes the extension of the previous work on mounting several of these elements in an array configuration. As a part of the basic study, the coupling effect between two wideband monopole has been studied, helping to evaluate the effect on the global behavior of the array elements weighting functions.

Passive arrays have been realized in 7-10 GHz frequency band. One is based on a H type configuration fed in its center including 6 crossed monopoles. It exhibits a bandwidth of 1.5 GHz centered at 7 GHz with a matching better than 10 dB and a radiation multi beam pattern with a maximum gain of 15 dB.

The second type is centered within the ISM band and based on a four orthogonal feeding lines configuration. These one are feed separately with power dividers placed backside. An active version of this last configuration is also proposed using integrated amplifiers independently fed.The different bias voltages permit to give more or less gain to the amplifiers therefore to arrange the diagram according to the desired configuration.

The calculation of the basic array configurations have been performed through a commercially available software NEC [5] in conjunction with WIPL [6].

General consideration on the design procedure will be given during the conference either for single basic element or array configuration.

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Rigorous Analysis of Transient Radiation Mechanism of Small Multi-Sector Monopole Yagi-Uda Array Antenna Using FDTD Method

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The Multi Sector Monopole Yagi-Uda Antenna (MS-MPYA) shown in Fig. 1 can be used achieve the low profile multi-sector antennas [1], [2]. The MS-MPYA needs to set metallic fins between arrays to suppress undesired radiation from adjacent arrays. The multi-sector configuration sharpens the beam width, so with metallic fins we can get the same level of directivity but with a shorter array than the One-Array model. However, the previous study did not determine the role of arrays adjacent to the main array, whether they work as reflectors, directors or something else when the main array is fed. Transient analysis is useful to examine the Yagi-Uda array antenna's radiation mechanism [4] because with that we can see how electromagnetic waves propagate on directors in real time.

To examine the above mentioned problem, this paper adopt transient analysis (namely FDTD [3]) for MS-MPYA. We have given an FDTD analysis model [5] for MS-MPYA to match both the experimental result and the MOM result. We show the time response of the current density z-component in Fig. 2. The delay pulse occurs at nearly 200 ps, caused by the fins. Up to 250 ps is first response of the pulse and from 250 ps the wave become stable near the resonant frequency.

The instantaneous distributions of electric field intensity are shown in Fig. 3 in the first response. We compare three types of model: (a) is a three-array model with fins, (b) is a one-array model with fins, and (c) is a no-fin tree-array model. When we don't use fin shown in the model (c), the electric field spreads and toward adjacent array. When we set metallic fins as shown in (a) and (b) the radiation propagates in the positive x direction. In (a) the wave propagates toward the adjacent arrays' directors from the main array's directors and reflects from them. So the Inner Electric field level of the directors is higher than the outer Electric field level. This is because the interval originates at the directors i.e., the center electric field's island stops at the adjacent arrays' directors. Therefore comparing models (a) and (b), the electric field level of (a) becomes higher than model (b)'s. This is the reason that the beam width of the adjacent array model is as slightly narrower than that of the one-array model. When we don't use metallic fins, as shown in model (c), the wave reaches adjacent directors not only from the center array's directors but also from previous directors in the same array. So the wave propagates in three direction.

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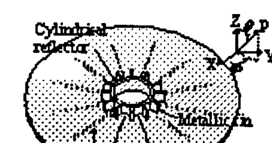

Fig. 1 Antenna Configuration

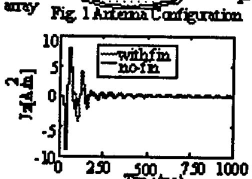

Fig2 Transient response of z-component of Current density Jz

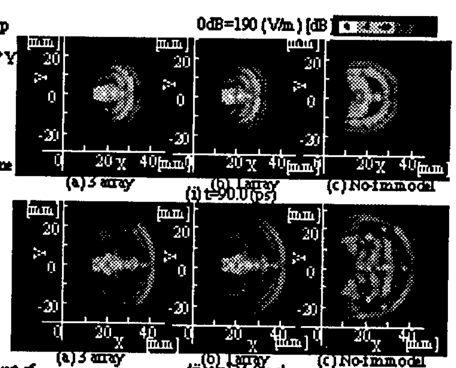

Fig3 Instantaneous distributions of electric field intensity

Spatial Filtering Technique for Radar Cross Section Control of an Array Antenna

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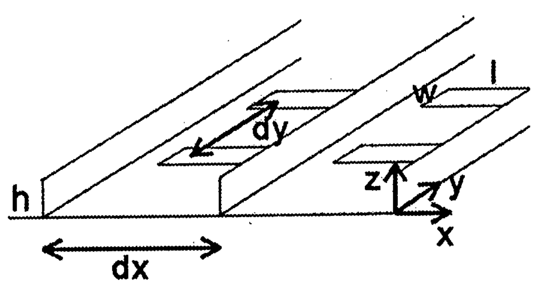
A spacial filtering technique for control of the radar cross section of an array antenna is presented. The approach is shown in the figure below where the (x, y)-plane represents the ground plane of a slotted waveguide array radiating into $z>0$. The slots, due to theirlocation in aoeriodic grid, generate grating lobes when illuminated from above by an external radar signal and this can lead to undesirable high radar returns. These lobes can be controlled by introducting thin conducting baffles (corrugations) of height h between the slots. Propagation in the region $0<z<h$ is then in the form of parallel plate wavequide modes. For certain ranges of incidence angles, frequencies and polarization these modes are cut-off so that the slots are'invisible' to the incident plane wave - the baffles act as a spatial filter.



A computer model based on the method of moments has been developed for the corresponding infinite periodic structure. In view of Floquet's theorem it reduces to essentially three cascades sections of multi-mode transmission lines. The model was used to design a set of spatial filters for an actual slotted waveguide array on which extensive radar cross section measurements were performed. In this presentation we will discuss the computer model along with theoretical and experimental results.

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Fractal Arrays and Lacunarity

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Introduction

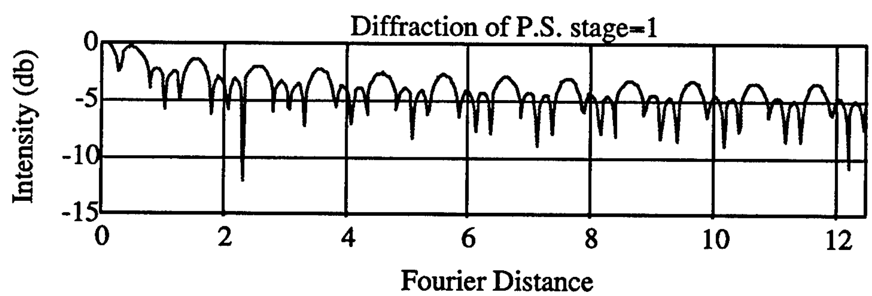
We examine radiation and diffraction by Cantor antenna arrays and apertures including a new class of Cantor targets based on a polyadic Cantor set described by several fractal descriptors including fractal dimension and lacunarity. We find the scaling properties characteristic of these apertures and examine their radiation patterns through the use of twist plots which allows one to find "windows" of lacunarity and fractal dimension for which these apertures exhibit desired behavior such as low sidelobes. We find these arrays have distinctive *subfractal, fractal* and *superfractal* radiation regimes with boundaries that can be predicted from the aperture geometry.

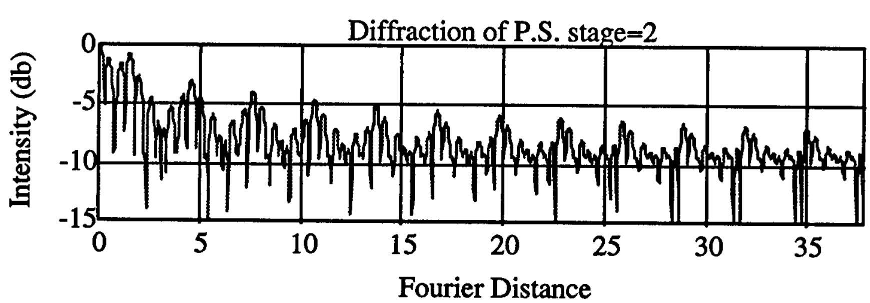
Fractals and Arrays

This work has applications to the synthesis of new arrays and apertures based on fractal geometry. The first work in this area considered the fractal distribution of array elements for robust, sparse linear arrays more than one decade ago [Y. Kim and D. L. Jaggard, "Fractal Random Arrays," *Proc. IEEE 74,* 1278-1280, (1986)]. Recent work has investigated fractal antenna elements as well as self-similar apertures and arrays. The latter forms the starting point for the research reported here.

Below is shown the diffracted field for a "Purina" fractal aperture at first (upper) and second (lower) stages of growth. Note the similarity of the patterns (one modulates a scaled version of the other) that is evidence of the self-similarity of the aperture array. We show how the descriptors of the generating Cantor set affect the radiation pattern. These descriptors include fractal dimension, lacunarity, stage of growth, and number of gaps – all of which are available to the designer of such arrays.

We note the use of lacunarity (or fractal texture) and its use in array design. We report on both the method and the physics of the problem in which the array radiation characteristics are connected directly to its geometry.





Session G07
Wednesday, July 15, AM 08:40-11:00
Room M
Microwave Components II
Chair : S. Toutain

An Adaptive Multigrid Method for Solving Poissons-Equation Applied to a Coplanar Meander Line

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A multilevel iteration technique has been developed for solving Poissons equation applied to 2 dimensional static field problems. This method is well established in many fields of numerical mathematics. However, the acceptance to solve electro-magnetic field problems is very poor. Therefore, the authors wish to give an insight into the theory and emphasis the convergence acceleration in comparison to conventional solvers like Gauss-Seidel, successive overrelaxation or the Jacobian method. There, the main drawback is, that these solvers are not capable to smoothen the low and high frequency modes of the error equally. Thus, the basic idea of multilevel relaxation is to find grids with different discretization levels, determine the solution on the finest grid, calculate the residual equation and restrict the error to the next coarser level. This will be repeated until the coarsest grid is reached. On the ascend branch (prolongation) of the iteration the solution will be interpolated from the coarse to the fine level and will be corrected by the error determined in the same level from the descend branch. This technique will be improved by an adaptive grid refinement, where the amplitude of the residuum is significant large.

Typical positions are edges of conductors. An application which is used to verify this method, is the coplanar meander line in figure 1. The cross section of the structure consists of 4 coupled lines on GaAs (length = 605 μm) and has been simulated with the adaptive multigrid method. The results of the computation are compared in figure 2 with the measurements up 67 GHz. The simulator will be extended to the 3rd dimension in the next step of the development.

Then it should be possible to model the bends with an increased accuracy.

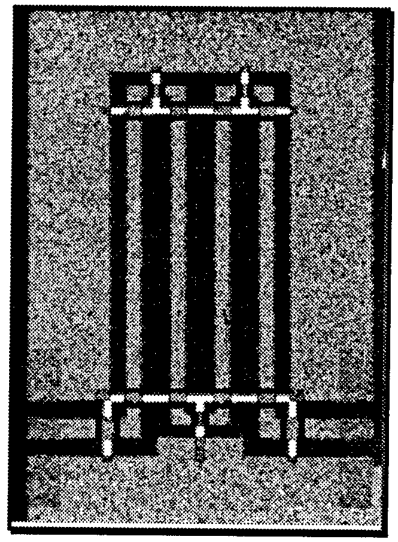

figure 1 photo of a cpw meander line

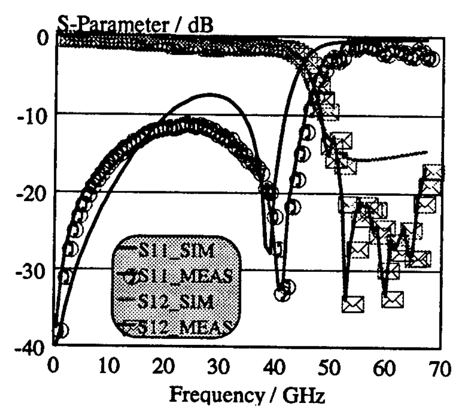

figure 2 measured and simulated results

Multimode Equivalent Network Representation for Multiple Arbitrarily Shaped posts in H-Plane Waveguide

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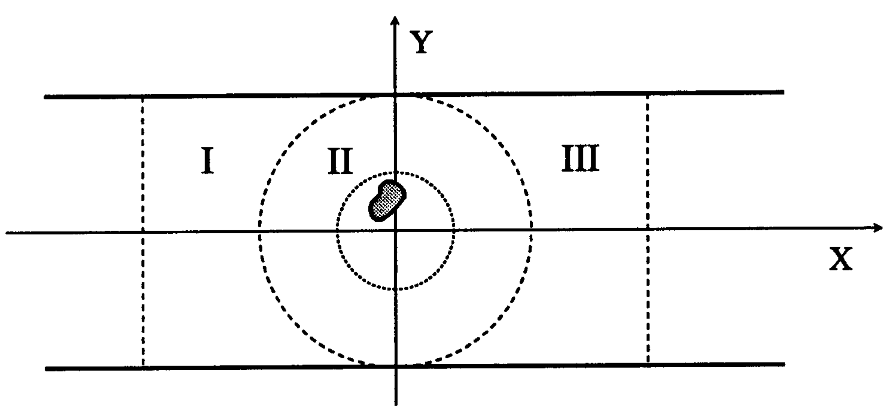
This paper presents a method for the calculation of the S-parameter of arbitrary shaped and composition post or group of posts in guide. The rigorous study of the dielectric posts in guide is of constant interest in the design of filters. In the methods currently available, the region that contains the post is analysed together with the post itself. This implies that in case of any modification in form, position or electric characteristics of the post, the problem would need to be analysed from the beginning, thus limiting its systematic calculation. The method that we propose segments the problem into regions. Each region is analysed independently by means of a generalized admittance matrix (GAM). The interconnection of the matrices brings us to the solution of the problem. This method has a double advantage. The first one is that one can use the technique that is best suited to the characteristics of the post. And the second one is that it avoids having to calculate once more those elements which were not modified.

In figure below shows the problem we intend to solve. In the interior of the rectangular waveguide there is a post generally not centered and of arbitrary section and composition. The most convenient segmentation is the one which establishes a circular contour around the post, because the field scattered by the post can be better expressed in terms of cylindrical waves. On the other hand, the propagation of these waves in the waveguide can be expressed more adecuately by means of the solution modes in its interior. In figure below shows the applied segmentation. Regions I and III carry out the necessary conversion of the cilindrical modes to plane modes and vice versa.

In region I and III an integral formulation based on wave equation solutions is used to generate the GAM. For the central region an analytical solution can be obtained basically by using cylindrical wave solutions and Graf's addition theorem for Bessel functions, though inhomogeneous obstacles would be treated numerically by Unimoment method. Some results will be presented. They show very good agreement with existing techniques.



Modeling of Spectrum Polarizers in Ridged Circular Waveguides

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Polarizers are an important key building block for many communications systems. The polarizer can be realized using various designs. The usual Polarizers are often designed in square or circular waveguide. In this paper, we present a new approach to modeling septum polarizer in ridged circular waveguides. This type of polarizer offers an advantage in that the need for an ortho-mode transducer is eliminated. The septum polarizer combines the function of the ortho mode tranducer and the polarizer. For the characterization of septum polarizer, two steps can be carried out. Firstly it is necessary to determine the differrent types of the transitions. Secondly, after having characterized each discontinuity, the overall transmission through the septum polarizer can be obtained by considering the cascaded ridges circular waveguide discountinuities. Then the different ridged circular waveguide dimensions can be optimized to obtain the required response. Our analysis method is based on integral equation with a scalar Green's function in combination with an improved variational multimodal formulation. The cutoff wavenumbers in ridge circular waveguides are calculated using ascalar eigenvalue equation with a scalar Green's function for circular resonator. Therefore, boundary element method is only applied over ridge's contour instead of cross section. This technique allows to calculate the coupling coefficients straightforwardly - without cumbersome integrations - from the matrices already used in cutoff wavenumber's determination and by using only longitudinal fields. Variational multimodal formulation is improved to determine impedance matrix of a discountinuity instead of scattering or admittance matrix. The impedance matrix obtained in this way is of small size. Overall scattering matrix is obtained from the individual impedance matrices. The phase shift between modes is deteminated by adjusting the length of the septum steps. In order to verify our approach, three septum polarizers are optimized for frequency 3.7 to 4.2 GHz, 5.4 to 6.1 GHz and 7.6 to 9.4 GHz and results are verified by measurements.

Circularly Bent Slab Waveguides Bounded by Electric Walls

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Bent waveguides are essential for directional change in optical systems and integrated guided-wave devices. Propagation characteristics in bent waveguides have been investigated for many years, especially because of their relevance to pure bending loss [1]. Although real optical waveguides have finite cladding thickness, most of the researches have been done for waveguides with cladding of infinite extent. The finite cladding thickness leads to oscillatory transmitted power as a function of the bend radius and wavelength, because the radiation waves emitted from core region are reflected from outer cladding surface and interfere the core guided mode [2],[3].

In this paper, we present the approximate but quite accurate method for analyzing circularly bent slab waveguides and compare the propagation characteristics by the method with those by the conventional method. The conformal transformation technique has been used in many researches to replace a circularly bent waveguide by a straight waveguides with the inhomogeneous index profile dependent on the bend radius [4]. We referred the method using conformal transformation as the conventional method. On the other hand, there is no approximation in our method, except for replacing the unbounded configuration by a corresponding one for which the bounds are electric walls [5]. The normal modes of circularly bent slab waveguides bounded by electric walls are numerically obtained by the Runge-Kutta method and are sufficient to expand the input wave from straight waveguide. The modal-matching method is applied to satisfy the boundary conditions at the junction of bent and straight waveguides [5].

The pure bend losses estimated by the present method and the conventional method are found in good agreement and slightly less than that estimated in the reference [1]. However, when the interference of reflected waves are involving, the transmitted powers by these methods are quite different. It comes from the fact that the optical path length is not correctly estimated in the conventional method even for planar structures. The present method is possible to apply to bent slab waveguides with finite cladding thickness. The results will be also shown.

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TM-Polarized Nonlinear Non-Kerr-Like Guided Waves in Asymmetrical Dielectric Slab

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During last years semiconductor multilayer systems have been extensively studied because of their crucial role in various all-optical switching devices. These systems exibit very strong nonlinearities, which are an essential prerequisite for the formation of nonlinear guided waves (NGW's) along the interfaces of layered structures.

However, the principal efforts were initially concentrated upon the investigation of TE-polarized waves propagating along single-film structures and power-dependent dispersion relations were derived for spatially-stationary guided waves. In this case the electric field has only one component and therefore a simple analytical solution can be obtained.

For TM-polarized fields, the occurence of two electric-field components, one pointing parallel and one perpendicular to the interfaces, complicates the theoretical analysis and only in few articles one can found the numerical calculations for TM-waves. Moreover, in many real materials permittivity varies with the electric field rised to a power other than two, so detailed investigation of arbitrary nonlinear waveguides is necessary.

In this work we present analytical solutions for both components of TM-polarized electric field in arbitrary nonlinear media with permittivity given in the following form:

$$\varepsilon = \varepsilon_0 + \alpha |\mathbf{E}|^{2\delta} \quad ,$$

where $|\mathbf{E}|$ is the magnitude of the electric strength, ε_0 - a permittivity of the material for $|\mathbf{E}| = 0$, α is an arbitrary constant, and δ is an arbitrary real number. In the case of a TM-polarized electromagnetic field two first Maxwell equations integrals for both components of the field are obtained and the general solution is expressed in terms of elliptic integrals. Using the analytical expressions for the field components the dispersion relations are derived and the propagation characteristics are discussed.

As an example, GaAs-AlGaAs three-layer structure, which consists of a thin linear film of thickness d and permittivity ε_2, a linear cover with a permittivity ε_1, and a semiinfinite nonlinear substrate, is considered. The propagation conditions of TM-waves and the field structure in such system are studied.

It was shown, that there are allowed parameter regions for propagation constant, where various modes of TM waves can exist. The width of these bands depends on linear dielectric constans and thickness of the structure.

Thus, our theory offers the opportunity to study all propagation characteristics of TM-waves in any nonlinear waveguid structure.

Electrodynamical Characteristics of Confocal Open Superconducting Resonators

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New mathematical methods for solving the boundary value problems for open superconducting structures are developed and justified based on the theory of spectral operators. This enables us to solve a number of important application problems.

In this paper, on the basis of ideas [1 - 4], confocal open superconducting resonators with rectangular and circular mirrors are considered for the first time. Method of solving of this third kind boundary value problem amounts to system of integral equations. Obtained solution is expressed via spheroidal wave functions and depends on the surface impedance of superconductors. Mirrors containing thin superconducting films in their structure are also discussed. Use of superconducting films allows one to reduce losses and to improve characteristics of resonators.

Asymptotic relations for propagation constants and Q-factors of the discussed resonators are obtained. For some particular cases numerical results are presented and compared with characteristics of resonators with normally conducting and perfectly conducting mirrors.

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Session G08
Wednesday, July 15, AM 11:00-12:40
Room M
Photonic Band Structures

Organisers : D. Maystre, G. Tayeb
Chairs : D. Maystre, G. Tayeb

A new FDTD approach to study PBG structures : Application to parabolic reflectors.

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Since researchers have understood that Photonic Band Gap materials (PBG) can be designed to offer the properties expected, they are very interested by this new kind of dielectric materials. Indeed PBG can either reflect electromagnetic waves on a broad frequency bandwidth or filter a narrow bandwidth in its frequential gap if the material is engineered with a particular defect. This idea to built such materials comes from a crystallography experiment. One day scientists noticed that some particular crystals are able to reflect X rays whatever the direction of the incident wave. An investigation linked this phenomenon to the periodic arrangement of the atoms in the crystal. The concept of PBG was born. In 1987 Yablonovitch proved the feasibility of PBG in millimeter frequency range [1] and some years later he built the first three dimensional PBG material. He copied the diamond structure by drilling holes in a dielectric block. He made experiments and observed the same phenomenon in the millimeter frequency range : in a broad bandwidth, the wave was totally diffracted by the structure. Since 1987 lots of works have been achieved to understand the behavior of PBG. Researchers have adapted their electromagnetic theories and method to study these structures (theoretical methods [2,3], numerical approaches by FDTD [4] or finite elements). One of the method we used is FDTD [5]. With a such tool we study PBG on very broad bandwidth and we obtain very reliable results. Nevertheless the sizes of the structures are often several wavelengths and the spatial FDTD discretisation consumes much memory, so we have developed a time surface impedance formalism to model PBG on broad frequency bandwidths.

An analytical surface impedance model is first built in the frequency domain. This impedance is composed of a sum of physical filters. Then a time expression of the surface impedance is obtained by the Fourier transform of the analytical model. We finally make the convolution between the time impedance and the electromagnetic fields in the FDTD algorithm. The model we have developed uses a recursive method to calculate the convolution product by the temporal impedance.

This new concept of surface impedance is then used to model a PBG parabolic reflector by its surface impedance in FDTD codes. The performances of such antennas will be shown and compared with the performance of the same metallic reflector when losses are neglected.

Conclusion :

This new formalism of surface impedance applied to PBG structures is an interesting improvement to study PBG on very large bandwidth. This approach has allowed to study a three dimensional structure which can't be discretised using a FDTD mesh grid.

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Electromagnetic Scattering Solution of a Finite 2-D Dielectric Photonic Band Gap Lattice

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We present frequency-domain calculations, and confirming experiments performed at microwave frequencies, of plane-wave scattering from finite periodic arrays of dielectric cylinders. The scattering is computed at various angles from the incident normal. Distinct signatures of the infinite-lattice photonic bandstructure are evident from the scattering spectra, including frequency bands of attenuation, corresponding to Photonic Band Gaps (PBG); frequency bands of transmission, corresponding to propagation bands; and sharp resonances, possibly corresponding to band edge resonances. Studies are made on square lattices containing up to one hundred cylinders (10 x 10).

The numerical simulations utilize the Generalized Field Propagator method, developed by Martin, Gerard, and Dereux. In this method the scattering Greens function for the entire system of scatterers is iteratively, and self-consistently, developed. Using this technique allows us the ability to compute the steady-state scattering from a finite PBG structure, with arbitrary dielectric contrast, and with complex dielectric function. While these initial tests and comparisons are done for a two-dimensional geometry, the numerical method is easily adapted to study general three-dimensional structures. Furthermore, the excitation is not limited to plane-wave, but can also, for example, be a point-dipole in 3-D or a line current in 2-D. We anticipate that a point source next to a finite PBG structure will serve as an effective model for the planar antenna problem.

Finally, we present initial calculations of steady-state emission from a line current excitation in or near a finite 2-D PBG lattice. We perform this calculation directly, using the incident field of a line current as source, and compare the results to measurements made in a microwave scattering chamber.

Channel Drop Filters in Photonic Crystals

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Channel drop filters are important components for wavelength division multiplexing in optical communication systems and photonic integrated circuits. One generic class of the filter structures is composed of two waveguides, side-coupled through a resonator system which supports several localized states. Such devices allow the selective transfer of a single frequency channel from one waveguide to the other, while leaving all other channels unaffected. Photonic crystals offer an ideal medium for constructing such filter structures. The waveguides are introduced by carving out line defects, while the resonator system is introduced by creating point defects. These defect structures are compact. Their sizes are typically on the order of the wavelength. Furthermore, the coupling strength between the defect structures can be easily adjusted by tuning either the geometric properties or the dielectric constant of the crystal structure. In this paper, we introduce the specific characteristics required for the resonator system to achieve complete channel drop tunneling. We show that complete transfer can occur between the waveguides by creating localized states of different symmetries, and by forcing an accidental degeneracy between the localized states. The degeneracy must exist in both the real and imaginary parts of the frequency. In the case where the resonator system supports two modes with opposite symmetry, the transfer function possesses a Lorentzian lineshape. More complex lineshapes, such as the maximum flat function, can be generated by employing more than two resonances, and by adjusting the frequency and width of each resonance appropriately. We illustrate the results of the analysis by performing finite-difference time-domain simulations on the transport properties of electromagnetic waves in a two-dimensional photonic crystal. We demonstrate a single-mode transfer with a quality factor as high as 6,000, and with a maximum flat transfer lineshape.

Experimental and Theoretical Comparison of Photonic Crystals Transmission Properties

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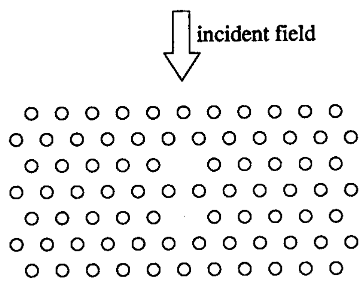
An anechoic chamber, recently constructed under the supervision of our Laboratory, provides us the opportunity to compare our theoretical modeling of photonic crystals with experience. Here, we are concerned with a two-dimensional dielectric photonic crystal made with rods of circular cross section. The crystal possesses an hexagonal symmetry and can be doped by removing some of the rods (see figure).



The theoretical investigation is performed with the help of a rigorous modal method [1], [2]. Basically, the scattering matrix of the complete set of rods is derived from the knowledge of the scattering matrix of each rod, which leads to the resolution of a linear system. The rods are considered as infinitely long.

The experimental measurements are realized in the frequency range going from 2 to 6 GHz. The crystal is placed between two antennas (emission and reception) in an anechoic space. The relative permittivity of the rods is equal to 6, the filling ratio (proportion of dielectric) is 0.083 (diameter of the rods: 10 mm, distance between the centers of the rods: 33 mm).

Concerning the two transmission peaks which appear in the gap due to the defects, a perfect agreement between theory and experiment is observed. On the other hand, the limits of the gap are much more dependent on numerous parameters. Indeed, the theoretical modeling does not exactly reflects the experimental conditions, and we will particularly discuss about the influence of the choice of the incident field.

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Theoretical and Experimental Study of Metallic Photonic Band-Gap Materials : a Multiple Scattering Modeling

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There is a number of recent papers showing that a new class of periodic dielectric structures, the photonic band-gap materials, may have many potential applications, particularly in the conception of planar antennas. In these materials, electromagnetic wave propagation in any direction is completely prohibited for all frequencies within a stop band.

An iterative algorithm has been developped to calculate the propagation of electromagnetic waves in such very heterogeneous structures [1]. With this algorithm we can take into account the coupling effects between the inclusions of the material (spheres or cylinders) whatever their size with respect to the wavelength may be. In the case of photonic band-gap materials, the lowness of interactions allows to consider only the first or second order scattered fields [2]. So, without numerical problems, it is possible to describe structures with an important number of inclusions.

Various photonic band-gap materials have been realized with metallic and dielectric cylinders. Bistatic free-space measurements, performed from 4 GHz to 18 GHz with a vectorial network analyzer are compared to the simulations.

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Session H04
Wednesday, July 15, AM 08:40-12:20
Room R02
Recent Advances on Complex Materials and Related Applications
Workshop on Complex Media and Measurement Techniques

Organiser: L. Vegni

Chairs: L. Vegni, J.P. Parneix

"Angular Window" of Propagation in Wire Media

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Recently, we theoretically introduced ideas for newclasses of novel complex materials that we have named *FeedForward/FeedBackward* (FF/FB) Media and *Wire* Media [1-4]; both media seem to exhibit interesting spatial dispersioncharacteristics. The FF/FB media, which exhibit *macroscopic* spatial feedback, can be conceptualized by envisioning a conventionalartificial material (formed by embedding many small inclusions within somehost medium) and then linking pairs of inclusions by means of tiny transmission lines. The wire media, which consist of many parallel,finite-length, identical wire inclusions, can be characterized by tensorialmedium parameters that have clear dependence on the direction ofpropagation. This dependence results from allowingthe wire inclusions to have any arbitrary length, from a fraction of awavelength to a length comparable to the wavelength, since for conventionalartificial materials, where the inclusions are taken to be small comparedto the wavelength, the tensorial elements of material parameters (e.g., dielectric tensor elements) do notusually show variation with direction of propagation.

Based on our theoretical analysis, one interesting consequence of spatialdispersion for loss-less wire media is the possibility of exclusion of wavepropagation from certain angular regions; essentially, wave propagation isrestricted to certain "angular windows" that depend upon the chosen design parameters (e.g., numberdensity, orientation, length, and volume fraction of inclusions). Furthermore, these media are frequency dependent and, beinguniaxial, interact differently with different wave polarizations. In otherwords, like frequency-selective surfaces and filters, wire *media*effectively behave as *angle-selective volumes and filters, frequency-selective volumes andfilters,* and *polarization-selective volumes and filters.*Consequently, these media may find some potential applications in design offuture microwave devices and components, such as substrates formicromachined and miniature antennas, radome for beam shaping, and waveguides for modeselection. In this talk, we will present our theoretical results on severalsalient features of wire media, including the property of "angular window"of propagation, and we will discuss physical insights into these results.

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Radiative Features of Gyrotropic Structures : Theory and Practice

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This work illustrates a comprehensive investigationon the theoretical and practical properties for a significant class ofdevices making use of gyrotropic substrates.

In our previous analyses [1-3], new interesting anduncommon phenomena have been emphasized as concerns the propagation and theradiation effects in basic topologies showing nonreciprocalcharacteristics, such as those ones based ongrounded transversely-magnetized ferrite layers. In particular it has beenemphasized that, under precise conditions, a simple current line source cangive rise to beams which can be highly directional in wide angular ranges and can be controlled by varying severalparameters (frequency, magnetization, etc.). Moreover, it has beendemonstrated that these radiative effects can conveniently be investigatedand understood in terms of improper and proper complex branches of 'anomalous' modes.

Starting from this knowledge, we have considered in further details otherimportant radiative properties useful from both a theoretical and apractical standpoint. These investigations are founded on a rigorous butsimple electromagnetic characterizationobtained by introducing a suitable transmission-line formalism [4], whichallows us to use an efficient spectral representation of the problem basedon the Green's function of the structure.

Some original aspects for the radiation performances of grounded gyrotropicsubstrates are considered in both qualitative and quantitative ways,highlighting the relevant peculiarities and the differences with isotropiccases. The nonreciprocal properties of the structures under investigation are illustrated first by examiningthe transmitted and the received powers that are radiated at anglessymmetrically with respect to the broadside direction. Even making use of asingle anisotropic layer it is shown the capability of reaching very narrow beams scannable over awide forward/backward angular range. Such a high directionality isinvestigated referring to a transverse-resonance approach [5,6] properlyextended to nonreciprocal structures.Important validations of the leaky-wave contributions are deduced by theexcellent agreement concerning the beam pointing directions. Also, a rayoptics analysis can be considered to reach a simple description of thenonreciprocal directional properties of these components.

In addition to these aspects, the actual possibility of achieving a gainenhancement is analyzed by evaluating the efficiency of such radiators,considering both the power properly radiated in the far field and the powercarried away by the excitableguided modes. Evaluations of these powers have been led in order tooptimize gain, thus identifying the most advantageous positions of thesource element inside the structure. Finally, it is very interesting toconsider the practical consequences on the radiation due to the ohmic losses in the media. The analysis shows inwhich extent directivity and gain can be altered and what kinds of basicmodifications from the ideal case have to be taken into account. Theresults of this study furnish a fundamental background for the practical use of anisotropic substrates in thepresence of sources for radiating purposes.

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Microstrip Resonator on the Chiroferrite Substrate

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Recently the interest has been drawn to artificial composite materials, exhibiting chiral and nonreciprocalproperties [1]. Since some of these composites may be used in hybrid andmonolithic microwave integral circuits, the reason appears to develop therigorous electrodynamical methods for calculations of microstrip lines and discontinuities on bianisotropicsubstrates.

The full-wave spectral-domain method for solution ofthe boundary-value problems for two-dimensional microstrip grating embeddedinto multilayered bianisotropic medium hasbeen developed [2]. In this paper the method is applied to the numericalstudy of the perfectly conducting microstrip rectangular resonator on thenonreciprocal chiroferrite substrate. The resonant frequencies andradiative losses as functions of the direction of tangent magnetic bias field and the chirality parameter areinvestigated.

Two cases may be separated here. In the first one,the resonant frequencies lie outside the magnetostatic modes (MSM) band,the radiative losses are small and the variation of the magnetic bias field direction causes the tuning of resonant frequencyon 2-5%. The influence of chirality parameter is less than of the magnetic fielddirection.

In the second case, when the resonant frequency falls within themagnetostatic modes band, the radiative losses strongly increase and smallvariations of the magnitude or direction of the magnetic bias field causesessential tuning of the resonant frequency within MSM band.

Thus, an example of solution of three-dimensionalboundary-value problem for planar bianisotropic structure is presented and the properties of themicrostrip resonator on chiroferrite substrate in a wide range of themedium parameters are studied.

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On Fundamental Symmetry Aspects in Electrodynamics of Microwave Bianisotropic Composites

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In microwave region, chiral and bianisotropic materials are composites. A novel class of microwave bianisotropic materials has been conceptualized recently. There are particulate composites based on small magnetostatic-wave ferromagnetic resonators with a special-form surface metallization [1], [2]. A fundamental symmetry framework gives insight into novel properties of proposed *quasistatically controlled* bianisotropic composites and provides distinguishing between these materials and other types of bianisotropic composites.

a) **Symmetry aspects of bianisotropic particles.** Contrary to an analysis in [3], in our case one can not consider separately geometric symmetry and microscopic symmetry properties of materials (ferromagnetic). We are talking about symmetry properties which provide invariance of solutions for quasimagnetostatic potential. We have to discuss explicitly symmetry properties of bianisotropic particles under rotation, spatial inversion, time reversal, and combined symmetry transformations (inversion and time reversal).

b) **Symmetry in constitutive parameters of bianisotropic media.**Thermodynamical analysis of symmetry properties used for magnetoelectric crystals is not applicable for microwave bianisotropic composites. For alternating fields, the principle of kinetic-coefficient symmetry has to be used [4]. The principle of kinetic-coefficient symmetry was used in [5] to characterize constitutive parameters of bianisotropic composites described in [1], [2]. Contrary to [5], our analysis is based on careful consideration of linear-response properties and continuity-equation form of the energy balance equation in bianisotropic media [6]. It is shown that symmetry of constitutive parameters should be considered together with the symmetry configuration of the electromagnetic field.

c) **Symmetry properties of bianisotropic crystal lattices.** Magnetoelectric crystals exhibit their properties since combined symmetry transformation (inversion and time reversal) takes place. In proposed bianisotropic composites [1, 2] physical properties may be invariant to the time reversal. Some of these properties are applicable for an analysis of bianisotropic crystal lattices [7].

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On the Measurement of Material Parameters of a General Bianisotropic Medium

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In the last decade, considerable progress in the development of measurement techniques for characterising composite materials,especially isotropic chiral media with three complex material parameters,has been made [1 however, the experimental approaches used today give noway of finding all 36 comp ex components ε_{ij}, α_{ij}, β_{ij}, μ^{-1}_{ij} i,j = 1,2,3 of material tensors $\varepsilon, \alpha, \beta, \mu^{-1}$ of a general bianisotropic medium which, at frequencyω is characterised by the constitutive relations $\mathbf{D} = \varepsilon\mathbf{E} + \alpha\mathbf{B}, \mathbf{H} = \beta\mathbf{E} + \mu^{-1}\mathbf{B}$. In[2]-[5] the covariant Impedance methods in electrodynamics of motionlessand uniformly moving linear media are developed, and the exact solutions of the inverse scattering problemsfor such media are found. In this paper, a measurement technique forcharacterizing general bianisotropic media is suggested and the results ofits computer modelling are presented. The modelling consisted of two stages. At first, by making use of theimpedance and characteristic matrix methods Fresnel's coefficients ofreflection and transmission of bianisotropic slabs, cut off from a materialwith given material tensors $\varepsilon, \alpha, \beta, \mu^{-1}$,have been calculated. At the second stage these Fresnel's coefficients have beenused as the input data in solving the inverse scattering problem, and thecalculated material parameters have been compared with the given ones.

The obtained results show that the suggested measurement method makes itpossible to calculate all 3s material parameters of a general bianisotropicmedium from the measured reflection and transmission coefficients. Thevalidity of this method is supported over a wide range of material parameters values. The stability of the solutions of the inverse problem withrespect to small variations (experimental errors) of Fresnel's coefficientsangles of incidence, orientations of interface normals and planes ofincidence is investigated. The optimization of the measurement setup is discussed, and the requirements Imposed onthe measurement accuracy are formulated. It is shown that the materialparameters of some complex media can be sound by the measurements undernormal incidence. The distinctive feature of the suggested method is the fact that it is based on the use of theexact solution of the inverse scattering problem, obtained with verygeneral assumptions, namely, the linearity and the microscopic homogeneityof the medium. Therefore, It is applicable for characterlzing various natural and artificial complex media atboth microwave and optical frequencies.

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Leaky Modes in Chiral Rib Waveguides

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The rib waveguide is an *open*dielectric structure commonly used in integrated optics [1]. There is anincreasing interest for open dielectric chirowaveguides in the design ofnovel chiral devices with potential applications in integrated optics[2].

In this paper we present a new class of*leaky modes* that can propagate in a chiral rib waveguide. The occurrence of such leakymodes is well-known in the literature for common isotropic waveguides [3].Nevertheless, the existence of leaky modes in chiral rib waveguides is presented herein for thefirst time. One should note that the study of the leakage effect is ofutmost importance in the design of novel devices, as well as to preventcrosstalk which may deteriorate the system performance. In any case it is important to know whether or not agiven chiral waveguide can propagate leaky modes. Moreover, one shouldstress that these modes are completely different from the semileaky modesthat the authors have analyzed in [4].

The chiral rib waveguide under consideration is a open dielectric structurewith the following cross section: (i) a central region consisting of achiral film surrounded by a cover and a substrate both of a commonisotropic media; (ii) two identical lateral regions with the same structure as the central one, but with a smallerthickness of the chiral film. Within the central region we assume that two elementary surface waves canpropagate. Due to the chirality of the film these elementary surface wavesare coupled hybrid modes. Moreover, since the central region is located betweenthe two outside regions, these two surface waves will bounce back and forthhorizontally in the inside region undergoing total internal reflection ateach bounce.

We show, using an approximate analysis in which the radiation modes areneglected, that the two elementary surface modes of the central region will couple at the strip sides and that - underappropriate circumstances - this coupling gives rise to leakage in the form of an exiting surface wave. Therefore, when a guided mode of the rib waveguide istransformed into a leaky mode, its longitudinal wavenumber becomes complex.Curves for the attenuation constant (due to the leakage effect) as afunction of the strip width are then presented for several values of the chirality parameter and for the firstleaky mode above cutoff of the chiral rib waveguide.

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Artificial Magnetism of Composites on the Base of Dielectric Resonatorinclusions at Microwaves

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Composite materials are an object of detail investigations nowadays. Somecomposites are matter of great interest in microwave science since they canbe perspective materials for applications due to their effectiveelectromagnetic parameters. Usually suchcomposites are loaded by conductive wire inclusions of different shape(helices, closed and unclosed rings, omega-particles, etc.). As a rule theunwrapped wire length of the inclusions is taken close to the half of the free-space wavelength of an incidentradiation and composite materials loaded by such inclusions exhibitresonance electromagnetic properties at microwaves.

In the present work we investigate a compositematerial on the base of a new inclusion type. We elaborate and examinecomposite materials loaded by dielectric resonators. Dielectric resonatorsare well-known in microwave engineering and their properties are studied thoroughly, but the composite materialloaded by dielectric resonators is a new object for investigations. The composite underinvestigation is the chaotic arrangement of resonators on the thindielectric substrate. The resonators are made of high permittivity materialand as a sequence its size is small in comparison with the free-space wavelength when its principal mode is in*S* or *X* band. The principal mode of thedielectric resonator is the *TE* (magnetic) mode thus the composite material under investigation has to gainthe resonance effective magnetic properties at microwaves although it haszero DC permeability. Cubic and spherical dielectric resonators were usedfor manufacturing composite samples. The resonators were made of ferroceramics $BaTiO_3$ f20. The real part of microwave permittivity of this material varies from 400 to3000 in dependence on annealing temperature of the material. Tangent ofdielectric losses is about $tg\delta \approx 0.1$ at microwaves.

We deal with single-layered composite materials andthe possibility of characterization of single-layer planar composites in terms of complex effective parameters is a problem underdiscussion. We carry out experiments that demonstrate that the descriptionof these particular composites by the complex permittivity $\hat{\varepsilon} = \varepsilon' + i\varepsilon''$ and complex permeability $\hat{\mu} = \mu' + i\mu''$ is physically sound.

Using a free-space experimental setup, the effectivepermittivity and permeability of planar composite materials were measuredat a wide frequency band (2.5-18 *GHz*). From the experimental data we can see that the samples underinvestigation possess the effective artificial permeability of theresonance character. We characterize this permeability resonance with theresonance frequency f_m, the resonance half width ν_m and the resonance amplitude $A = \mu''(f_m)$. Besides, we examine the dependence of the effective permittivity andpermeability on the inclusion concentration. In this case the experimentaldata for the permittivity obeys conventional Lorentz-Lorenz formula. Thevalue $A = \mu''(f_m)$ increases with the rise of inclusionconcentration, reaches its peak and then decreases. The concentration dependenciesof the resonance frequency $f_m$demonstrate decrease when the inclusion concentration increases. Thesedependencies can be explained through the interaction among separateinclusions. The experimental results demonstrate that the lower the valueof the real part of the inclusion permittivity the stronger interaction among them.

Finite Element Solution of Theelectromagnetic Vector Wave Equation for Bianisotropic Media

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In solving boundary value problems involving inhomogeneous arbitrarily shaped objects, the techniques offinite difference and finite element have been used extensively in therecent years. When compared with other numerical methods such as theintegral equation technique or the method of moments, these methods require less computational time and less storageowing to the highly sparse and banded matrices involved. One disadvantageof the finite methods, however, when applied to solve open regionscattering problems is the necessity of anartificial boundary surrounding the scatterer, to allow the region betweenthe boundary and the scatterer to be subdivided into meshes. When such anartificial boundary is present, one always has to impose an absorbingboundary condition (also known as impedance boundary condition) at this boundary in order to solve theelectromagnetic problem. The objective, in fact, of the absorbing boundarycondition is to truncate a differential equation solution region withboundary conditions that cause minimum reflections of an outgoing wave. These boundary conditions should, also, providesmall, acceptable errors while minimizing the distance from the object ofinterest to the artificial outer boundary. The minimization of the distanceis required to reduce the number of unknowns in the problem, improving, then, the efficiency ofcomputation. There has been a lot of research done over the recent years onabsorbing boundary conditions for the two dimensional (2-D) case, and,also, some for three dimensional (3-D) case. The purpose of this paper is to present an absorbing boundary condition(ABC) derived from the integral equation solution of a scattering probleminvolving complex media like the biisotropic chiral ones. The integratedstructure may comprise any number of layers. The patch may be of arbitrary shape. Hence, using the approachdeveloped here, microstrip patch antennas of various, possibly irregularshapes, residing in multilayered (lossy or lossless, dispersive or nondispersive, isotropic and/or bi-anisotropic) integrated structures, may be analysed within a single formulation,using the same computer program.

The result is an accurate ABC, based on field values on a surface enclosingthe sources, which makes the artificial boundary virtually invisible tooutgoing waves. The method presented is not dependent on the position ofthe source and on the complexity of the media involved and does not put any restrictions on the outer boundaryshape. One more advantage is the decrease in sparsity of the system ofequation to be solved.

Numerical results are compared with existingpublished data to verify the finite element code.

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Nonlinear Faraday and Kerr Rotation in Magnetic Media

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A few years ago it was reported about observation of nonlinear behavior of the Faraday rotation angles in the semimagnetic semiconductorCdMnTe Refs. [1], [2], as well as in the ferromagnetic semiconductorCdCr{2}Se{4} Refs. [3], [4]. Theoretical description of the nonlinear Faraday rotation waspresented in our papers Ref. [5], [7], as well as in Ref.[2].

The present communication is devoted to the theoretical investigationof the effects of electromagnetic wave polarization plane rotation induced by the intensity of incident light in magnetic media. Thesephenomena are considered for two possible geometries (in reflection as wellas in transmission) i.e. nonlinear Faraday and Kerr effects (NFE and NKE).NFE and NKE are nonlinear analogs of usual Faraday and Kerr effects in linear optics.

For calculations we take into account the cubic nonlinear polarizationin magnetic media. Contributions of electronic and magnetization inducednonlinear optical susceptibilities are considered and compared. Analytical expressions for angles of nonlinear rotation were obtainedand analyzed.

Numerical estimations of corresponding values were made.

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Transverse Propagation of Plane Electromagnetic Waves in a Gyrotropic Uniaxial Omega Medium

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On a level with small helices, tinyΩ-shaped wire particles are basic elements formanufacturing artificial composite materials with the magnetoelectriccoupling. These planar inclusions when embedded in an isotropic host mediumgenerate certain bianisotropic composites, such as planar omega, uniaxialomega and pseudochiral media and structures.

To date matrix media for the omega composites areisotropic ones as a rule. If such omega inclusions arearranged within a gyrotropic medium. there appears a new bianisotropicmaterial combining the features of gyrotropy and electromagnetic activity. Like aFaraday chiral medium this is able to exist in two forms (with gyroelectricor gyromagnetic matrix media). Such complex bianisotropic media can possessnovel interesting properties on microwaves (provide control of the magnetoelectric-coupling level etc.).

We consider a bianisotropic composite medium inwhich omega shaped elements are combined in two sets of orthogonally positioned particles ("hats"). They areplaced in such a manner that stems of all elements are perpendicular to apreferred direction (we choose the z-axis) and all loop portions of the elements point either to the +z or -zdirection. A host gyrotropic medium (a semiconductor magnetoplasma or amagnetized ferrite) has as a distinguished direction the z-axis. So, themedium turns to a uniaxial omega medium if the static magnetic field vanishes, and becomes a gyrotropic mediumif the only parameter of magnetoelectric coupling tends to zeroPhenomenologically, the medium is described by two constitutive relationson the base of the Post-Jaggard formalism.

Plane-wave propagation in the unbounded medium canbe considered by inserting assumed eigenvalue fieldfunction with the exponential factor $\exp[j(\mathbf{k}\cdot\mathbf{r} - \omega t)]$ in the Maxwell equations together with the constitutive relations and bysolving a determinantal eigenvalue equation for the wave vector **k**. We examine here the propagation across the imposed magnetic field. This important special case provides the Cotton-Moutoneffect in gyrotropic media and gives an additional pass band in achiroplasma. There can be two eigenwaves which are allowed to bereferred as modified ordinary and extraordinary plane waves. Their wavenumbers are investigated on the plane of the reducedgyrotropy parameters along with fixed values of the coupling parameter (the pseudochirality admittance). Although the medium isassumed to be lossless, the wave numbers may admit real, imaginary, orcomplex values. In the case of gyroelectric version of the medium, analysis of pass and stop frequencybands permits to discover ten topologically diverse types of thefrequency-plane diagrams. In the case of more simple gyromagnetic version, there is no dependence on the frequencyparameters of the medium for the propagation coefficient of the ordinarywave.

J. I. P. R. 4 - Session I04
Wednesday, July 15, AM 08:40-12:20
Room 200
Ultrawideband (VHF - UHF) Polarimetry

Organiser : E. Pottier

Chairs : S.R. Cloude and L. Ulander

Development and Operation of the FOA CARABAS VHF-SAR System

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Two versions of a VHF SAR concept have been realized, the original CARABAS I instrument and the new upgraded CARABAS II sensor. The frequency segment 20-90 MHz has been selected in both cases, with the polarization utilized restricted to HH. The most striking part for both systems are the antenna arrangement, a five meter long suspended dipole structure trailing behind the aircraft for CARABAS I whereas a push boom construction, of the same dimensions but mounted on the nose and pointing forward, was developed for CARABAS II. The experimental testbed CARABAS I was fielded during 1992 to 1994. Six major campaigns were conducted with this sensor at environmentally different test sites. A lot of ground truth data were collected simultaneously during each experiment and most often additional SAR sensors were imaging the same area. One of the first tasks addressed was the need to investigate appropriate reference targets to deploy for calibration purposes. Trihedrals, logperiodic scatterers, an active transponder system and dipole arrays, containing elements at various heights to provide information about the multi-path effect, are among the test targets used during the initial experiments.

The first three campaigns focused on foliage penetration (FOPEN) studies and included deciduous (Ottenbylund), coniferous (Siljansfors) and rain forest (Fort Sherman, Panama), respectively. During these occasions no flight data were recorded and, consequently, no motion compensation has been applied in the ground based signal processing. This has reduced the number of useful synthetic apertures to those exhibiting small deviations from a straight flight line. A differential GPS system was for the first time introduced in connection to the campaign at Yuma Proving Ground, AZ, aiming at imaging arid areas with low frequencies and examine the potential for ground penetration. A mixed forested area at Portage Lake, ME, concluded the measurements at the three test sites located in the western hemisphere, and carried out under sponsorship from the Defense Advanced Research Projects Agency (DARPA). The last mission for CARABAS I was to do simultaneous measurements with ERS-1 over the Baltic sea ice (Farstugrunden) to identify if any significant advantages could be found when interpreting images based on longer radar wavelengths compared to the satellite C-band data presently used daily by the office responsible for ice monitoring.

The overall results from CARABAS I were a major breakthrough in the field of ultra-wideband (UWB) SAR imagery, especially for foliage penetration studies and detection of targets hidden in deep foliage. The application of ground penetration was found to be a much tougher task to investigate. Any possible weak response present from buried targets was in most cases probably precluded by the image noise floor and not detected with the system performance figures available for CARABAS I. Technical limitations in the data recording capability introduced an ambiguity in Doppler above 65 MHz but, fortunately, the antenna characteristics on the other hand was also found to be poorer at the highest frequency segment. In addition, the lifetime of each trailed antenna was limited and since it was difficult to manufacture them with identical electrical characteristics this meant that a stable standard calibration procedure of the radar images was not easy to develop and apply on a regular basis. Only a few CARABAS I images have been calibrated carefully, e.g. from the Ottenbylund forest stand where the initial biomass estimation work were carried out. Despite of the system performance degradation present the obtained promising results for a future operational use were convincing and funding to develop an upgraded system were granted.

The work on assembling the new CARABAS II sensor was finalized in 1996, a joint effort with Ericsson Microwave Systems AB. Except for the antenna system the main improvements concern the use of two receivers simultaneously to overcome the sampling requirements in Doppler, a larger dynamic range in the receiving chain, a delay line between the antennas during the transmission phase to steer the main illumination pattern to one side and, finally, a digital waveform generator to modulate each individual transmitted pulse arbitrarily in the used stepped frequency scheme to span a pre-defined total bandwidth within the interval 20-90 MHz. Apart from the hardware development four different processing algorithms for UWB VHF data have been implemented in a UNIX workstation environment, one of them also parallel in its structure and thus ported to a multi-processor system available. Simulation software tools are under development to be able to retrieve the expected radar responses from various scatterers for comparison with real SAR signatures, e.g. trihedrals, trucks or forests.

A number of campaigns has been conducted with CARABAS II. A very flat agricultural landscape located on an island (Visingsö) has been selected for system calibration studies. Seven trihedrals have been deployed at different ranges and by gathering data from several parallel flight paths a large number of well-defined signatures at different incidence angles has in this way been registered along the full synthetic aperture, which for a VHF SAR can be considerably long. Foliage penetration and target signatures were studied in the BALTASAR experiment, where the DLR E-SAR system was operated in parallel at X- and P-band over both a coastal and inland area in southern Sweden. CARABAS II participated in the experiment Keystone 97, which took place in Pennsylvania and was a multi-sensor demonstration with tactical ground order of battle deployments under sponsorship of DARPA. The joint French-Swedish campaign RAMCAR98 focused on two different forested areas in France where the RAMSES system, operated by ONERA, added X- and L-band to the data collection. The two sites, Les Landes and Lozère, are very well documented from a number of radar and optical sensors, and forest parameters such as biomass, tree heights and age are well known. Some targets were deployed and obscured by foliage also in this case. A dedicated forestry experiment, EUFORA, funded by the European Union were carried out in Finland in 1997. Together with a Swedish test area (Tönnersjöheden) data from the four European sites contain a variability of woody biomass between 0-1000 m^3/ha. Included in the described data sets are also synthetic apertures realized as a full circle, multi-baseline interferometry collections, repeated imaging for change detection investigations, and data acquisition at high altitudes where the impact from radio frequency interference (RFI) should be more severe and thus more demanding for the mitigation algorithms.

Multifrequency Polarimetric Radar System in the Low VHF Band

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Future requirements of air defense radar systems are detection, localization of aircraft, but also identification and discrimination. Due to the increasing stealthy behavior of new military aircrafts, these requirements become more difficult to achieve. The HF-VHF multifrequency and multipolarization radar, called MOSAR (Maquette Orientée pour un Système d'Analyse de Résonances), is a new approach trying to provide new insight into the field of air defense radar systems. The MOSAR radar works in the metric band (20-80 MHz) with four simultaneously transmitted frequencies and two polarizations, horizontal and vertical.

This system which is currently in its final stage, has been developed by the Laboratoire Structures Rayonnantes/Radiocommunications (Université de Rennes 1), with the support of the French DGA and in collaboration with IRESTE (Université de Nantes), LTSI (Université de Rennes 1), ONERA and THOMSON-CSF/AIRSYS.

The M.O.S.A.R. system is a coherent, pulsed, quasi-monostatic, HF-VHF radar. Two different antenna arrays are used for the transmitter and the receiver. System parameters are given in table 1. The 40 ms pulsewidth corresponds to a minimum range of 6 km and the 400 ms interpulse period yields a maximum unambiguous range of 60 km.

	System characteristics
Transmitter :	
Frequency band	20 - 80 MHz
Number of frequencies	4
Peak pulse power	2 kW/polarization
Average power	200 W/polarization
Pulse width	40 ms
Interpulse period	400 ms
Antenna Arrays :	
Polarization	horizontal and vertical
Beamwidth	≈ 20°
Directions	elevation : + 5° to + 60 ° azimuth : - 60° to + 60°
Receiver :	
Bandwidth	30 kHz
Minimum input level	- 140 dBm
Dynamic range	72 dB
Noise figure	≈ 6 dB

Table 1 : MOSAR radar parameters.

Many measurements have been made on heavy commercial aircrafts, for different frequencies, and for horizontal and vertical polarizations, and cross-polarization. These measurements were performed on different days and we obtain, for the same type of aircraft, a good reproducibility of the measurements of received power. We present and discuss results obtained with four frequencies and two polarizations. The results confirm the interest of using frequency and polarization diversities.

Polarimetric RCS Signatures of Commercial Aircraft in the HF Band

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The knowledge of RCS fluctuations of radar target is necessary to improve the recognition methods. Lots of models of aircraft RCS have been implemented in high frequencies by means of optical approximation, but it is more difficult to determine the RCS in the resonance range.

This study has been made in the context of a project named MOSAR (Maquette Orientée pour un Système d'Analyse de Résonances). MOSAR is a HF-VHF multifrequency and multipolarization radar ; it is used to measure the Radar Cross Section (RCS) of aircrafts in the 20-80 MHz frequency band, with the objective to test identification methods. Therefore, it is necessary to develop a RCS model of commercial aircrafts in this frequency band.

At HF frequencies, wavelengths are in the region of aircraft dimensions, in the resonance range. The moment method allows the modelling of an aircraft in this frequency band. To calculate the RCS, the electromagnetic software, NEC2, was used. It is built around the numerical solution of integral equations for the currents induced on the structure by sources or incident fields. Several simulations for a Boeing 747-200 commercial aircraft have been performed (Figure 1). The RCS is determined by wire-grid modelling of the structure. To grid this aircraft, we have used about 3000 segments.

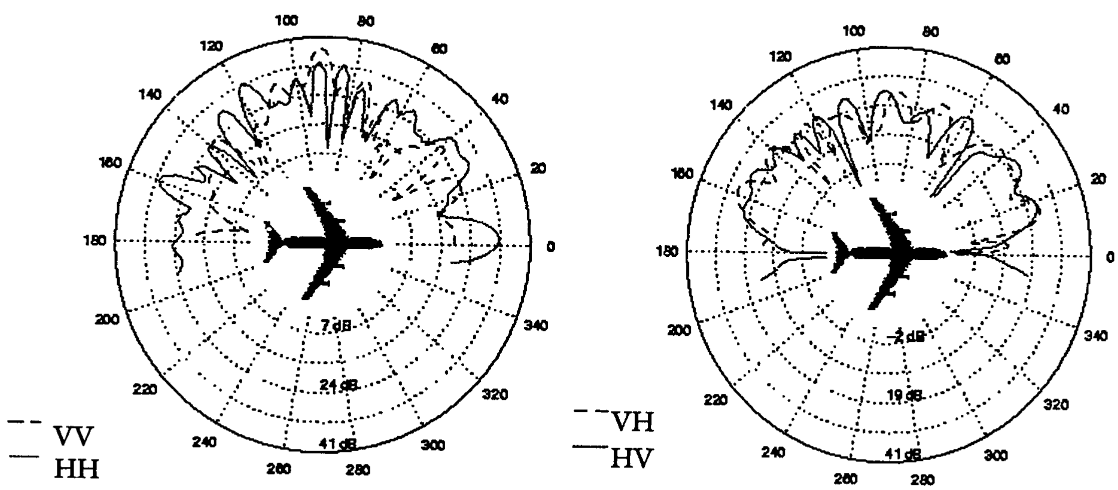

Figure 1 : RCS simulations of a Boeing 747-200 at 20 Mhz.

The fluctuations of RCS have been studied as a function of azimuth at several frequencies. The different terms HH, HV, VH, VV have been compared. Usually vertical polarization seems more discriminating than horizontal one. The advantage of this model is to allow the determination of the aircraft impulse response. On the whole, the simulations present a good agreement with the measurements made in an anechoïc chamber.

The major limitation of wire-grid model is the difficulty to obtain the RCS at high frequencies. Indeed, the number of segments is restricted by the memory space of the computer. Thus, actually, the model is limited to frequencies under 40 MHz.

Advances in RP-UWB-POL-D-InSAR Technology : Reapet-Pass Ultrawideband Polarimetric (Scattering Matrix) Differential Interferometric Synthetic Aperture Radar Image Overlay (Stress-Change) Interferometry

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During the past decade, *Radar Polarimetry* has established itself as a mature science and advanced technology in *high resolution POL (scattering matrix)-SAR imaging, image target characterization and selected image feature extraction.*

More recently, with the addition of single platform SAR interferometers Digital Elevation Mapping (DEM) was made possible for both air- and space-borne TOPographic SAR systems, operated primarily at the X, C, L, and P bands. *SAR Polarimetry* and *SAR Interferometry* are marging in that polarimetric (scattering matrix)-Interferometric (POL-InSAR) imaging systems are currently being perfected to become truly Ultra-Wide-Band (VHF-to-EHF : 100MHz-to-100GHZ) *UWB-POL-InSAR* imaging systems which with the implementation of advanced D-GPS and IGU navigational autosteering of the imaging platform resulted in high-accuracy Repeat-Pass Differential (*RP-UWB-POL-D-InSAR*) Image Overlay interferometry. In addition, by implementing UWB holographic principles direction-sensitive in-depth focused geo/eco-environmental stress change imaging through the conopy into the foliage overburden and into non-conductive soils becomes feasible. Concurrent with rapid development of these phenomenal *RP-UWB-POL-D-InSAR imaging systems*, basic polarimetric-interferometric-SAR image feature characterization, sorting, and focusing algorithms were also rapidly advanced opening the gateway for solutions to many noveln hitherto untreable geo/eco environmental stress-change remote sensing problems. Various fundamental and applied issues of these « *RP-UWB-POL-D-InSAR Holographic Imaging Techniques* » will be adressed, and complemented by applications to geo/eco-environmental stress change monitoring of the terrestrial vegetative terrain and ocean surf zone covers by implementing the best avaiblr « rp-UWB-POL-D-InSAR image data sets » collected with air/space-borne SAR imaging systems available from NASA-JPL, ESA-STEC, DCRS-EMI, DARA-DRL, NASDA-EOS.

Determination of Specific Frequencies of an Aircraft Model in Order to Identify Real Size Targets Using a V. H. F. and Polarimetric Radar

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The radar signature of a target can be extracted from the knowledge of incident and backscattered wave polarization states. The modification of the polarization state of a transmitted wave is modeled by a two-by-two complex matrix : the Sinclair matrix. From this matrix it is possible to determine the nine Huynen parameters which are linked with geometrical properties and structure of the target.

The principal aim of this study is to define the optimal frequency carriers of the low frequency and polarimetric M.O.S.A.R. radar, operating from 20 to 100 MHz. Using both such a facility and adequate polarimetric tools, discrimination of the polarimetric signature of the target and then identification of airplanes can be realized.

In this paper, we present a polarimetric identification approach of a reduced size aerial target (a Boeing 747-200 at scale 1/100°) measured in an anechoic chamber in the monostatic case, using the principle that a target presenting a Radar Cross Section (R.C.S.) of 1 m^2 (70 cm long) observed in the 2-10 GHz frequency band corresponds to a target presenting a R.C.S. of 10,000 m^2 (70 m long) observed in the 20-100 MHz frequency band.

Our original and adapted polarimetric method is based upon process using Huynen parameters and leads to automatic plot of the polarimetric pseudo-spectrum of the observation. This interesting graph highlights carriers with a marginal behavior.

As, in a real configuration scheme, the aspect angle of the target around the radar is unknown in site and in orientation, results are presented with respect to these two angles.

The analysis of the polarimetric pseudo-spectrum points out the fact that most of marginal frequencies are harmonics from a particular carrier, which corresponds to half the wavelength of the aircraft model.

Knowledge Aspects in Radar Polarimetry

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Lately, there has been some developments which demand attention and a new critical evaluation, which prompted the following discussion. At issue are two approaches to radar target polarimetric analysis which are referred to as incoherent and coherent addition of terms. We will show in this report that this distinction creates an artificial barrier by introducing competing development. Hence only a single process is necessary which can deal with the so-called coherent case via the (2x2) target-scattering matrix SM, as well as with the so-called incoherent case attributed to the (3x3) radar target coherency matrix H. We shall retain only the (2x2) SM and the (3x3) H matrices, while avoiding all statistical terminology. It turns out that by doing so, some processes and theories developed for pure coherence or incoherence can now profitably be used independently of the statistics.

For example, an important physical property of single targets deals with ATOMISM. A single target cannot be cut into two or more independent pieces, each of which represents different single targets, i.e., a single target is ATOMIC. This concept will be elaborated upon.

Another basic concept is that of a PHYSICAL target. A physical target is independent of absolute phase. A physical target can be moved by a small amount (jitterrd), within on RF wavelength, in a direction along the line of sight of the target. A physical target is JITTERPROOF. In other words, small changes in absolute phase do not change the physical nature of the target. Even if no such jittering of a component part of a single target ever is contemplated, it may be thought as being feasible in providing « jittered » target-scattering behavior interesting and new property which the H matrix satisfies : $H^2 = H$, which is ht basic equation for a system of knowledge which the author previously has studied extensively [1].

Référence

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The Influence of Polarization on the Performance Of High Resolution Methods

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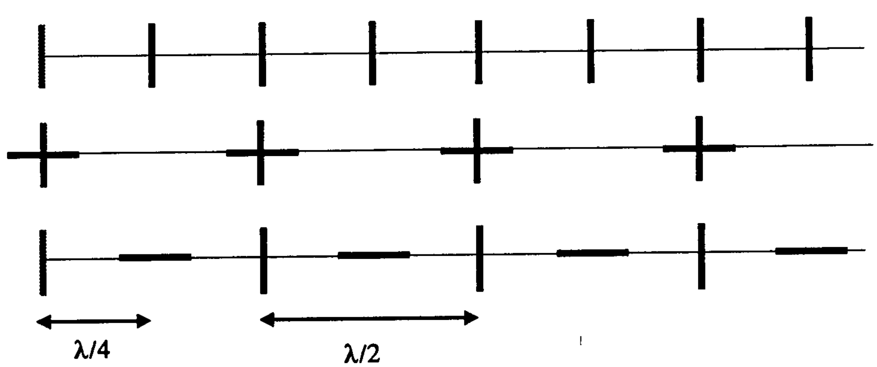
Diversely polarized antenna arrays have some inherent advantages over uniformly polarized arrays, since it is possible to separate signals based on their polarization characteristics. Polarization diversity has been used quite successfully in radar systems to greatly improve the performance of traditional systems working with a single polarization [1].

The problem of estimating the direction of arrival (D.O.A.) of signals impinging on uniformly polarized antenna arrays has been intensively studied in the recent past. The most successful methods such as MUSIC, ESPRIT and their many different variations have been extended to the situation of antenna arrays with polarization diversity [2].

In this paper, we consider the influence of polarization on the performance of the high resolution methods. The ESPRIT method [2] is calculated and simulated for three different structures of the array of sensors in terms of different polarizations of incoming waves. This method allows the estimation of the direction of arrival and the polarization of the incomng waves simultaneously.



We have investigated the performances of a uniformly polarized antenna array and two diversely polarized antennas arrays shown in the above figure. We have shown that polarization diversity enhances the performance of DOA estimation: both accuracy and resolving power are improved. In order to assess the performance, we have calculated the Cramer-Rao Bound (CRB). The CRB enable us to establish the theoretical limits of the unbiased estimators and to foresee the DOA estimation accuracy. The simulation results confirm the theory and give an quantitative idea about the performances of these methods. Then we studied the performances of estimation of the polarization parameters of incoming waves by two diversely polarized arrays.

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Session J08
Wednesday, July 15, AM 08:40-11:40
Room 450
Forest Observations by Radars : The Eufora Project

Organiser : T. Le Toan

Chairs : T. Le Toan, S. Quegan

Radar Results from EUFORA Remote Sensing Campaign of Boreal Forest in Finland

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A combined airborne and spaceborne remote sensing campaign on radar remote sensing of forest was conducted in Tuusula, Finland, in June and September 1997 in the framework of the EU-funded EUFORA project. The test site is a typical southern boreal forest zone area, including coniferous and mixed forest canopies, clear-cut areas, mires, bogs, and lakes. The maximum forest stem volume is 300 m^2/ha. The test site is located near the Helsinki Airport and it provides good access to teams conducting ground truth measurements.

Airborne data was collected by the HUTSCAT ranging scatterometer on 6 and 12 June, and by the CARABAS SAR on 30 September. Spaceborne data includes ERS-2 SAR images acquired on 1, 12, and 17 June. Ground truth data was collected on weather parameters, soil moisture, vegetation moisture, canopy gaps and branch orientations, soil roughness, and vertical canopy profiles. Weather conditions were stable on all data collection days without any precipitation.

A standwise field inventory was carried out in the test site during the summer of 1997, including information on stem volume, mean height, basal area, mean diameter, species, development class, and age. The stand boundaries were imported to GIS.

This paper presents radar results from the campaign as a function of forest and soil parameters. Experimental data are compared against backscatter values from our semiempirical model.

Preliminary Analysis of HUTSCAT Data Over Austrian Pine Plantations in Relation with Tree Parameters and Architecture

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Helicopter-borne ranging scatterometers such as the HUTSCAT system proved to be efficient to measure tree height and stem volume along transects with sufficient accuracy for many forest applications. However, forest canopy backscatter profiles obtained from HUTSCAT are not fully understood and exploited for application purposes. Therefore, such promising data should be analysed in details over a simple forest such as even-aged homogeneous coniferous plantations. Moreover, this analysis should be supported by very detailed ground truth and tridimensional canopy information, followed by theoretical modelling using RT models that can accomodate the vertical variability within the crown layer. The final goal is the development of robust semi-empirical models for the estimation of relevant forest parameters for various applications.

Within the European project EUFORA, an HUTSCAT acquisition campaign was designed over pine plantations in Lozère, France, for which ground and forest parameters, stand limits and a DEM were available in a GIS. In particular, detailed 3D tree architecture is available through a tree growth model called AMAP. HUTSCAT was flown on October 22 and 23 1997 along few transects crossing many stands of homogeneous even-aged Austrian pine plantations (age 0-140), using two incidence angle modes : nadir and 23°. For each transect, the flight track was accurately positioned using differential GPS measurements aboard the helicopter, allowing to process correctly backscatter spectras related to given stands and to integrate them into the GIS. Backscatter information derived from spectras, acquired at C- and X-band with HH, HV and VV polarisations includes : 1) vertical backscatter profiles (individual and averaged) for few stands with 65cm vertical resolution at 0° incidence, 2) ground and crown backscatter contribution and 3) usual total bacskcatter. Then, specific algorithms calibrated for a given site allow to derive mean tree height and stem volume. Finally, at the time of acquisition, soil and canopy moiture content was sampled for few stands.

In this paper, preliminary experimental results are presented and analysed. At the stand level, as previously reported, height and stand volume derived from HUTSCAT correlates very well with in-situ measurements. Ground and crown contributions are analysed as a function of stand age, soil moisture and canopy parameters. Of particular interest is the comparison of vertical backscatter profiles when the crown contribution is vertically well-separated from the ground contribution (older stands). In this case, the s° vertical profile (close to a bell-shape) seems to correlate with the vertical distribution of biomass within the crown, which is obtained from an allometric combination of density, diameter and length profiles given by the AMAP model. Next step will include a deeper analysis of these very detailed data, followed by RT modelling using the MIT/CESBIO model. This will permit a deeper understanding on the microwave interaction as a function of canopy depth (attenuation + scattering), towards the development of semi-empirical models to estimate parameters of interest such as biomass and volume.

EUFORA Data Collection with the CARABAS-II VHF-Band SAR

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CARABAS-II is an airborne SAR which operates in the lower VHF band (20-90 MHz) and uses horizontal polarization on both transmit and receive. The system is mainly designed for foliage penetration and detection of concealed man-made objects. The choice of frequency and polarization is a direct consequence of the fact that a typical tree trunk is vertical and has a diameter of a few decimeters, whereas the size of typical man-made objects is on the meter scale. Hence, by choosing meter waves and horisontal polarisation ensures both low attenuation and backscattering by the trees and a large scattering cross-section from man-made objects. However, it is also clear that the spatial resolution needs to approach the wavelength limit in order to resolve the man-made objects from the background clutter.

Another important application for CARABAS data is in forestry. The low attenuation combined with the fact that the dominant scattering objects are on the meter scale suggests that forest biomass or stem volume can be retrieved without experiencing the saturation effect as in the microwave or UHF bands. Depending on the resolution and image quality which can be achieved in practise, it may also be possible to identify single trees and detect changes between data collections.

As part the EU-project EUFORA a flight campaign was conducted over the Tuusula test site close to Helsinki on 30 September 1997. Five successful flight passes were completed, including four sides of a "box" and one offset track for interferometry. The radar waveform and nominal flight parameters are shown in the table below. The transmitted frequency band is slightly narrower than the system capability due to local restrictions. The bandwidth is split up into 33 sub-bands which are consecutively transmitted by pulse-to-pulse frequency stepping. A frequency notch is included in the digital waveform generator at 75 MHz to avoid interfering with the ILS marker beacon at the Helsinki airport. All flight tracks were performed with the same nominal altitude, velocity and track length.

Table. CARABAS waveform used for EUFORA mission

Frequency table	***Sequential (linear)***
Number of frequency steps	33
Centre frequencies	26.875 - 86.875 MHz with 1.875 MHz step
Frequency notch	74.8 - 75.3 MHz (ILS marker beacon)
RFI sniffing (TX off)	One frequency step every 34th PRI
Maximum range	15.7 km
PRF	7576 Hz
Flight track length	28.8 km
Nom velocity	100 m/s
Nom altitude	3 km

Forest Structure from Laser Profiling

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Active remote sensing is very sensitive to the geometry of the object in question. Therefore the structure of a forest is not only a parameter of interest, but also a parameter that affects the backscattering. Thus a microwave instrument having a suitable wavelength has potential in forest structure observation. The resolution of the satellite borne microwave instruments is usually rather coarse compared to the forest structure. Therefore it detects the structure only statistically. In order to model the microwave signature of a forest properly one has to be able to produce reliable forest structure statistics.

A helicopter borne 3D laser profilometer has been developed to study the crown structure, height variation and density of forests. A near infrared laser spot is spread with a lens to a horizontal line, that is then scanned over the forest. The laser line constitutes a vertical light plane, which then hits the topmost surface from crown to ground. This light profile is detected by an ordinary video camera, which is inclined so that it observes a perspective view of the profile. The flight altitude is below 50 m to give sufficient resolution and intensity for the scattered light. Another variation of the helicopter borne profilometer is a carborne instrument, the scans a vertical laser line along road sides or individual trees.

Examples of the profilometer results show the capability of the producing structural data by profiling instruments. Very precise individual tree profiles are used for modelling various types of trees. Vertical profiles of forest edges observe the variation of the air content in the forest as a function of height. The horizontal top profiles give information on the tree height distribution, density of the forest and crown shape. Results are shown for boreal forest of Tuusula, Finland.

Radar Backscatter Modeling of Forests Using a Refined Tree Architecture Model

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Theoretical modeling of the forest backscatter, is a powerful tool towards the development of quantitative forest applications using radar remote sensing. Electromagnetic models describe the forest canopy as a discrete media containing different classes of dielectric scatterers, corresponding to the various vegetation elements: trunk, branches and needles.

One of the major limitations of such models is the necessity to get detailed input parameters describing the medium. The overall quality of the simulated responses depends on the accuracy of the structural parameters feeding the model, especially when the involved scattering mechanisms are complex. Previous studies have been using ground measurement campaigns to provide input parameters. However, these parameters are usually difficult to estimate, especially because of the vertical inhomogeneity of the tree structure.

In this paper, we are using an architectural tree growth model called AMAP to provide the input parameters to backscatter models. This architectural model relies on both botanical and probabilistic concepts and is validated by ground measurements. The results of the electromagnetic models (MIT/CESBIO radiative transfer model and a coherent model based on a Monte Carlo approach) are then compared to experimental measurements over the Landes test site, using ERS, ERS Tandem, RADARSAT and SIR-C polarimetric data.

The use of this improved tree parameters description is shown to improve the results of the theoretical models with respect to the experimental measurements. Moreover, combining architectural and backscatter models gives access to a more refined electromagnetic description of the medium (attenuation and scattering profiles, phase center location) which are essential for the understanding of the interaction between the electromagnetic wave and the target medium.

A Comparison of DEM and INSAR Based Pixel-Size Normalization Methods for SAR Data over Hilly Terrain

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The true pixel size of SAR data over hilly terrain changes as a function of the terrain slope. As a consequence the backscattering needs to be normalized for the true pixel size in order to allow a more reliable quantitative interpretation. The geometric problem is well known. The terrain slope required for the radiometric normalization can either be estimated from a Digital Elevation Model (DEM) or based on the range and azimuth phase gradient of an interferogram.

For the first approach the problem is closely related to geocoding. The main problem is to determine the transformation between the range-Doppler and the map coordinates, taking into account the local terrain height.

For the second method the main problem is the estimation of the local phase gradients, i.e. the fringe rate of the interferogram. Due to the interferogram phase noise a trade off between spatial resolution and accurate gradient estimation has to be made. Larger estimator windows allow to reduce the estimation noise, but at the same time the spatial resolution is reduced.
ERS-1/2 Tandem pairs and a 50m resolution DEM over a hilly site near Lozere, France, were used to compare the two methods. The data are investigated in the frame of the European Forest Observation using Radars Project (EUFORA) with respect to forest mapping and the retrieval of forest parameters such as biomass and stand age. In particular for the parameter retrieval, a reliable pixel size normalization is very important. The problems arising with the different methods and the results achieved are discussed. We found, that the different methods lead to similar normalization factors for large parts of the scene. The interferometric method, however, shows serious problems in sections of very low degree of coherence. Therefore, the first method is in general more reliable. For sites without available DEM, nevertheless, the INSAR method offers a very useful alternative.

Multidate ERS Tandem Data Acquired over Hilly Forested Terrain : Influence of Biophysical and Meteorological Factors

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Recent studies have shown the great potential of SAR repeat-pass interferometry to discriminate forest from other land categories much easily than using classical backscatter intensities images. Among the sources of decorrelation, it is well known that the temporal decorrelation mainly due to targets geometrical changes is the most important. However, it is necessary to further study how these changes are related to topographic, meteorological (wind conditions) and biophysical parameters. Therefore, phenomenas that must be addressed are 1) direct and indirect topography effects, 2) the interaction between wind and trees and 3) the structural complexity of the media (tree parameters & architecture, canopy layers).

We analysed four ERS tandem pairs acquired during 95 and 96 on a test site located in the Lozère *département*, South France. This site, which covers 50 by 80 km, presents a great interest because of the variability in forest types and topographic conditions encountered. Most forest stands of various species are homogeneous and even-aged. We used a 50m grid size DEM, allowing to derive SAR local incidence angle classes, and an accurate digital forest inventory characterizing the land covers and forest types in more than 30 types. We crossed these informations in a GIS, and we extracted the behaviour of interferometric correlation (coherence) as a function of forest type and topography. In addition, we focused on Austrian pine plantations for which are available detailed forest parameters including biomass measurements. In general, we observe for a given acquisition a similar behaviour of all themes as a function of local incidence angle and a coherence decreasing with increasing stand density and amount of foliage, both linked to leaf area index (LAI). Of interest is the coherence behavior with growth stage, which shows a more or less rapid decrease with age. This can be explained by 1) decreasing ground backscatter contribution (highly coherent due to geometric stability) to the benefit of volume scattering (lower coherence due to wind effects) and 2) a diminished tree rigidity with age causing higher displacements and thus, lower coherence. These effects seem to be different for deciduous and coniferous species, depend on season and the LAI appears to be a key factor.

Then, we present a semi-empirical coherence model for Austrian pine trees, which takes into account the media vertical distribution in terms of tree parameters and architecture through a 3D tree growth model called AMAP. In addition, tree components displacements due to wind effects in the canopy are addressed, and are supposed to follow the vertical profile of wind turbulence within forest stands, as elaborated within theories of turbulent airflow for vegetation covers. The simulated coherence shows the importance of needles movements at C-band, and thus, a great sensitivity to the variables characterizing these displacements, which can be eventually related to LAI and aerodynamic roughness.

Change Detection Techniques Applied to Forest Monitoring by ERS SAR

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Single images of forested regions in ERS data often provide little scope for discriminating the forest from the non-forest areas, since the C band backscattering coefficient of forest is often very similar to that of non-forest areas. Multitemporal data offer two ways to improve this. Firstly, forest exhibits a comparatively stable backscattering coefficient, while agricultural areas and soils show considerable variation due to soil moisture and crop development. Hence temporal signatures offer a potential means of discrimination. Secondly, the speckle which impairs our ability to separate regions of similar scattering behaviour can be reduced by optimal combination of the multitemporal radar channels. This paper investigates how these properties can be turned to advantage, based on analysis of a full year's ERS data from a region of mixed deciduous and coniferous forest in West Harling, UK. The empirical basis of the analysis is the multitemporal behaviour of the constituent stands in the woodland. A forest stand map was made available to us by the UK Forestry Commission, which has allowed this behaviour to be described as a function of species and age. As well as indicating certain species differences (for example, between Corsican pine and beech) this also allows us to constrain the nature of the change detection and interpretation problem. Typically, in this region the forest has a backscattering coefficient lying between -11 and -6 dB with a maximum annual variation of less than 3 dB, while the surrounding agricultural areas show values outside this range and changes in excess of 4 dB. These values are derived making use of the known forest compartment boundaries, but we are interested in knowing how to exploit this information to locate the forest in regions where we have little or no ground data. To tackle this classification problem we need reliable methods to measure backscattering coefficient and its changes. This requires speckle reduction. We outline the approach most suitable for combining the 35 day repeat ERS images and illustrate the degree of smoothing this permits. Theoretical analysis allows us to estimate the number of independent samples needed to measure change in a time sequence with a given false alarm rate. In order to achieve this level, the multitemporal data must be further smoothed using spatial filters. Possible approaches to performing this operation are described and compared. In addition, when the image sequence is short, it may be more effective to smooth the data spatially before combining the multidate images, and we will present results from this approach. This will form the basis of a discussion about the minimum number of images, their timing and the image handling procedures needed to carry out the classification.

Session K04
Wednesday, July 15, AM 08:40-12:00
Room J
SAR Interferometry : Signal Procesing and Phase Unwrapping

Organiser : R. Bamler
Chairs : R. Bamler, H. Zebker

Phase Unwrapping Algorithms for Radar Interferometry : Residue-Cut, Least-Squares, and Synthesis Algorithms

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The advent of interferometric SAR for geophysical studies has resulted in the need for accurate, efficient methods of two-dimensional phase unwrapping. Inference of the lost integral number of cycles in phase measurements is critical for three-pass surface deformation studies as well as topographic mapping, and can result in an order of magnitude increase in sensitivity for two-pass deformation analysis. While phase unwrapping algorithms have proliferated over the past 10 years, two main approaches are currently in use. Each is most useful only for certain restricted applications. All these algorithms begin with the measured gradient of the phase field, which is subsequently integrated to recover the unwrapped phases. The earliest approaches in interferometric applications incorporated residue identification and cuts to limit the possible integration paths, while a second class using least-squares techniques was developed in the early 1990s. Here we compare the approaches and find that the residue/cut algorithms are quite accurate but do not produce estimates in regions of moderate phase noise. The least-squares methods yield complete coverage but at the cost of distortion in the recovered phase field. Synthesis methods, combining the cuts from the first class with least-squares solution, offer greater spatial coverage with less distortion in many instances. But even these fail to properly unwrap segments of interferograms. Future algorithms may reassemble the "islands" of error to form more complete solutions.

Global Minimization Methods for Interferometric Phase Unwrapping

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The goal of phase unwrapping is to find an estimate $\hat{\phi}(i,k)$ of the unambiguous interferometric phase $\phi(i,k)$ from its principal (wrapped) values $\psi(i,k)=W\{\phi(i,k)\}$ subject to some optimality criteria and a priori knowledge. Most of today's algorithms start from the popular *wrapped-differences-of-wrapped-phases estimate* $\hat{\nabla}\psi$ *of the phase gradient*:

$$\hat{\nabla}\psi(i,k)=\left(W\{\psi(i+1,k)-\psi(i,k)\},W\{\psi(i,k+1)-\psi(i,k)\}\right)^T$$

Being an estimate, $\hat{\nabla}\psi$ is prone to errors which will in general render it *non-conservative*:

$$r(i,k)=\nabla\times\hat{\nabla}\psi(i,k)\neq 0$$

and the integration of $\hat{\nabla}\psi$ will be path-dependent. $r(i,k)$ is referred to as the *residue field*. Finding $\hat{\phi}(i,k)$ is equivalent to finding its (conservative) gradient $\nabla\hat{\phi}(i,k)$ given the (non-conservative) $\hat{\nabla}\psi(i,k)$. Global minimization algorithms attempt to minimize the following difference:

$$\left(d_i(i,k),d_k(i,k)\right)^T=\vec{d}(i,k)=\left(\nabla\hat{\phi}(i,k)-\hat{\nabla}\psi(i,k)\right)/2\pi$$

subject to some constraints. In any case, $\vec{d}(i,k)$ must compensate the residue field:

$$2\pi\nabla\times\vec{d}(i,k)=-r(i,k)$$

Weighted Least Squares Estimation (LSE) algorithms perform the following minimization:

$$\min_{\phi}\left\{\sum_i\sum_k\left|\vec{c}(i,k)\cdot\vec{d}(i,k)\right|^2\right\}$$

where $\vec{c}(i,k)$ is a weighting vector. LSE is prone to severe errors caused by residues and tends to underestimate terrain slopes. Proper weighting can to some degree relieve these problems, but for correct phase reconstruction the weights must be chosen to be zero along the branch-cuts connecting the residues. Hence, also LSE techniques require knowledge about the branch-cut location.

Recently developed methods [1-3] restrict $\vec{d}(i,k)$ to *integer* values, i.e. they search for a solution that is congruent with the wrapped phase. Employing graph theory or network programming the following minimization can be carried out with relatively low complexity:

$$\min_{d_i,d_k}\left\{\sum_i\sum_k c_i(i,k)\left|d_i(i,k)\right|+\sum_i\sum_k c_k(i,k)\left|d_k(i,k)\right|\right\}.$$

These techniques have proven very robust. Phase unwrapping boils down to finding the 'right' weights $\vec{c}(i,k)$. We will discuss several weighting functions and how they can be used to incorporate different priors about the unwrapped phase (e.g. 'smoothest solution').

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Signal Processing as a tool for SAR and ISAR image interpretation

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Because of the unique association of an exceptional potential and a discouraging low quality, SAR images have drawn a great attention from the signal processing community in the recent years. This interest was first oriented towards speckle filtering with the intention to obtain, after an adapted processing, images of a quality similar to those obtained in the optical range domain. As this community was experimenting rather disappointing results in developing general purpose speckle filters, it turned towards more specialized signal processing operations, with the goal of performing specific functions in a given context.

This paper will present several different tools which have been derived to improve the use of SAR images or Interferometric SAR images.

The general philosophy of our methods is to make the most efficient use of the signal at the low level of the processing, and, at the same time, to take the greatest benefit of any available information. Powerful signal processing methods are available to day, therefore our efforts were to incorporate the available knowledge on the problem at end in a suitable form to be conveniently processed. Available information exists on the radar signal itself at the lowest level: it concerns models of radar signal and models of speckle noise which take into account the different possible hypotheses on the ground (textured or not).

This kind of information may be incorporated in different forms of detectors to produce foreseeable performances. We will present examples of line detections (for roads, rivers, lay overs), field detection, urban area detection to illustrate these techniques which are based either on adapted detectors or on Markov random fields.

Another level of modelling may be introduced in the spatial distribution of the elements of the landscape. Roads are linked in connected networks, layovers due to relief are often grouped in compact areas, urban are often distributed according to concentric areas with historic centers in the middle and industrial or commercial parts in the periphery, etc. This information may be incorporated in the global processing of the image to make it more robust to the ambiguity of the local detections.

Interferometric signal may be modelized as pure frequency 2D sine fields. From this model efficient detections of fringe orientation and spacing may be derived by spectral analysis. To have the detection robust to the DEM variations, pyramidal approaches are proposed, able to provide similar performances for very thin fringe regions, and for flat areas. A good knowledge of the fringe period and direction makes it possible to filter efficiently the fringes and make the interferogram interpretable even in rather noisy areas. Combining information issued from the SAR, the ISAR and the coherence images in a clever fusion scheme, it is possible to detect regions were the phase is likely to be unwrappable. Less reliable regions will be masked and ad hoc processes will be applied to make the best of neighboring reliable information.

Bayesian height estimation from InSAR using a fractal prior

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The phase unwrapping is the key step in recovering the terrain elevations from Interferometric SAR data. The problem is to find an estimate of the phase values known the wrapped noisy phase observations. Most of the previous work addresses the solution of the phase unwrapping stated as constrained least squares problem. Several authors have proposed multiresolution algorithms as computational efficient implementations of the phase unwrapping solution [1,2].

The phase unwrapping is an ill-posed inverse problem, the solution is not unique and depends on the prior knowledge encapsulated in the constraints introduced for the regularization of the solution. Recently solutions using quadratic regularization functionals and the Bayesian approach have been reported [3-6]. The Bayesian paradigm gives the frame to specify the complete set of prior knowledge: the forward model and the noise are represented in the likelihood term and the a priori information, i.e. the model for a desired solution, is specified by the prior term.

Hereafter we introduce a Bayesian model based solution for the phase unwrapping using a fractal stochastic process as a prior for the terrain height. The likelihood is the wrapping operator and the noise is assumed unknown characterized by the local variance. The implementation is a multiresolution algorithm. We use a Scene Understanding technique, that is find the scene which best explains the observed data.

The problem statement is: minimize an error measure between the observed and the simulated data. The simulated data are iteratively obtained using the forward model as a function of the current height estimate. The terrain height is obtained as a Maximum A Posterior (MAP) estimator, having as a prior information the fractal model. Due to the nonstationarity of the fractal process, and knowing that its differential process is stationary, correlated and Gaussian, we generate the prior model using a midpoint displacement method implemented in the wavelet transformed domain, i.e. we sample from a stationary Gaussian process and use the inverse wavelet transform to generate the guess of the terrain height. The MAP is obtained using an optimization by simulated annealing. The process is iterative at one scale and recursive in scale. In order to reach the optimality the fractal dimension is estimated from the observations, the wrapped phase, and the variance of the noise is estimated from the coherence of the interferogram. The proposed approach is confirmed by first experimental results.

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Evaluation of Bayesian Methods for Interferometric SAR Phase Unwrapping

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Phase unwrapping is a key problem in all quantitative applications of SAR Interferometry. It consists of the reconstruction of the absolute phase from its principal values. The absolute phase can be considered a function to be determined on a regular grid knowing its values modulo-2π.

It is well known that rotational inconsistencies in the principal phase gradient field are generated by random noise and undersampling. These inconsistencies affect the phase unwrapping and the quality of the derived DEM.

Several algorithms have been developed by our group to cope with these problems. In this paper we present and compare the results obtained using different methods.

The following approaches have been developed:

a) 2-D deterministic integration method, based on optimal strategies in pairing of opposite sign residues generated by noise;
b) filtering method based on a neural network approach for optimal pairing of residues generated by discontinuities in the phase field and by noise;
c) bayesian methods exploiting various optimization techniques, such as simulated annealing and genetic algorithms.

An endeavor is being done toward the implementation of some of the last mentioned phase unwrapping algorithm on parallel computers. In particular, a stochastic algorithm, properly modified in order to exploit in the best way the parallel architecture of the processor, has been implemented on an APE100/Quadrics (SIMD architecture). The phase unwrapping process has been formulated as a constrained optimization problem for a vector field of integers. The optimization problem is solved by a technique known as Parallel Tempering which allows an efficient implementation on the APE100 architecture. Experiments have been performed on simulated surfaces and on surfaces obtained from real scenes to show the effectiveness of the proposed algorithms.

SAR RAW Signal Simulation of Urban Areas

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In recent years there is a growing interest in the application of modern SAR techniques to study of urban areas [1], [2]. Urban settlements are often easily detectable on SAR images and SAR interferometry seems to be a very promising new tool to monitor changes in this dynamic environment. Unfortunately, in spite of the scientific community interest, few applications have been reported in the literature and, up to now, no quantitative evaluation seems to be possible. This is mainly due to the fact that the interaction mechanism between the electromagnetic field, radar system and man made features is rather complicated. In fact, whenever urban areas are under analysis, layover, shadowing and multiple reflection in the electromagnetic scattering dominate SAR data. This implies that SAR images interpretation and use of SAR interferometry are practically impossible at today state of the art, and it is necessary to develop appropriate models for SAR data formation mechanism. The first step could be implementation of this models in a numerical simulation code.

Recently, some SAR raw signal simulators have been devised [3], [4]. These were designed to deal with natural scenes, and cannot be used for this new environment. SAR simulators for natural scenes take into account layover and shadowing, but they only deal with rough surface single scattering contribution to the received electromagnetic field. Therefore, the main additional requirement of urban area SAR simulation is modelling of multiple scattering between buildings and terrain. The simplest way to match this requirement is use of Geometrical Optics (GO) and/or Geometrical Theory of Diffraction (GTD) applied to dihedral corner reflector-like structures. It is important to note that radar return from the multiple scattering path turns out to be time delayed with respect to radar return from the single scattering one.

Moreover, a SAR simulator for urban areas must carefully identify man made structures with respect to the surrounding terrain, in order to consider, for each scattering element, the appropriate electromagnetic parameter and surface roughness.

We finally remark the need for a preliminary identification of location and orientation of buildings' illuminated walls, so to identify, among all the dihedral corners, those effectively involved in the multiple scattering mechanism.

According to these guidelines, a new SAR raw signal simulator for urban areas has been designed. Canonical situations as well as simulation relevant to an actual case will be shown at the conference. Relevance of multiple scattering compared to single scattering mechanism will be assessed.

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Determination of City Models Using High Resolution InSAR Data

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High resolution Interferometric Synthetic Aperture Radar allows the generation of fully geocoded Digital Elevation Models (DEMs) and geocoded SAR images.

Due to the side looking geometry, shadows and layover areas appear and make the unwrapping and therefore the determination of a city model quite impossible tasks.

This paper describes a method for handling the shadows and loyover area and the determination of the city model using high resolution In-SAR data.

The first part of this paper presents a high resolution InSAR system of Aero-Sensing called AeS-1. It has the following parameters :

- Operating frequency: 9.6 GHz
- Baseline: 1.4 m (orthogonal to line of sight direction)
- System bandwidth: 400 MHz
- Ground resolution: 0.5 m x 0.5 m
- Swathwidth: 2 km
- Flight velocity: 100 m/s
- Flight altitude over ground: 3000 m

The second part of the paper presents the processing algorithms for obtainig the interferometric phase and SAR image in slant range.

The third part of the paper describes the algorithms used for phase-to-hight transformation and geocoding.

Finally results comparing the city model of InSAR and Photogrammetry are shown.

Error Analysis for Repeat-Pass SAR Interferometry : Applications for Deformation Analysis

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SAR interferometry has proven to be a valuable method for monitoring surface deformation. The repeat pass configuration enables the detection of deformations as a fraction of the applied wavelength. The retrieval of useful geodetic parameters, however, is limited by a number of error sources.

These error sources can be categorized into four kinds. Errors caused by the characteristics of the earth's surface are e.g. coherent penetration changes and temporal decorrelation. The second type of errors is caused by the medium in which the radio signals propagate, in particular the spatial and temporal heterogeneity of parameters influencing the refractivity, e.g. liquid water and water vapor. The third type of errors is influenced by the instrumental configuration: the SAR characteristics and the orbital parameters. The last type of errors is caused by signal processing limitations : both the SAR processing and the interferometric processing affect the quality of the final interferometric results.

This paper will give an overview of the main limitations in these four categories, the characterization and signature of the individual error sources, and their propagation into useful geodetic parameters. A first model will be presented to incorporate the influence of essential parameters and estimation procedures to estimate the feasibility of repeat-pass SAR interferometry for specific deformation processes.

Phase Unwrapping : Measures of Success

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This paper deals with the problem of evaluating the solutions produced by phase unwrapping algorithms. In the absence of ground truth data, how does one determine the quality or accuracy of the unwrapped solution? Typically, one has only the wrapped input phase and, in the case of IFSAR, a measure of the reliability of the phase data in the form of a correlation image.

In this paper, we propose some techniques for assessing the accuracy of the unwrapped solution. We begin with the observation that many phase unwrapping algorithms minimize an L^p-norm measure. For example, Ghiglia's PCG algorithm minimizes an L^2 norm, Costantini's network cost flow algorithm minimizes an L^1 norm, and Goldstein's branch-cut algorithm approximately minimizes an L^0 norm.

We propose an L^0 norm (weighted by the correlation values) as a natural measure of the quality of an unwrapped solution. However, this measure cannot be used blindly. Good solutions to phase unwrapping problems often have low L^0-norm measures, as one would expect, but poor solutions can sometimes have lower L^0-norm measures than good solutions. This surprising fact suggests that this measure may be more useful as a pictorial, rather than numerical, indicator of solution quality.

Because the L^0-norm measure is actually a count of the number of "discontinuities" (i.e., points whose elevations differ from a neighbor's by at least π radians) in the unwrapped solution, we propose the use of pictorial maps of these discontinuities, instead of the L^0-norm, to assess solution quality. These "discontinuity maps" indicate graphically where the solution has discontinuities. One usually expects discontinuities in regions of layover or decorrelation, but not in regions of well-defined phase values. Thus, if a discontinuity lies in one of these well-defined regions, it suggests the solution is incorrect in this region.

In the case of a solution produced by Goldstein's branch cut algorithm, the discontinuity map is nearly identical to the map of branch cuts. It essentially shows which paths of phase this algorithm did and did not follow in the course of unwrapping the phase. (Branch-cut algorithms follow paths around, but never across, the branch cuts.) Unlike the map of branch cuts, however, which can only be produced by branch-cut and mask-producing algorithms, the discontinuity map can be produced for *any* phase unwrapping algorithm. It is thus a suitable tool for evaluating the quality of any phase unwrapped solution, especially when combined with the correlation data or some other "quality map." Furthermore, the discontinuity map leads to more sophisticated techniques for detecting errors in the solution. These techniques are the topic of ongoing research.

Session L05
Wednesday, July 15, AM 08:40-10:40
Room R01
Local Area Network
Chair : L. Godara

Key Elements of IMT-2000

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First generation cellular systems combined switching and analogue radio communications to provide communications coverage to a large number of static and mobile users. In order to overcome the capacity problems associated with first generation systems, second generation systems were developed utilising digital radio transmission technologies. Despite the benefits associated with these systems, the continued increase in demand for cellular communications services could not be satisfied in many areas. In an attempt to overcome capacity problems traditional expansion techniques were utilised and, in addition, overlaid systems were developed to provide an overflow capability for new and handover cells. This concept of overlaid cells is further being developed in proposed third generation systems, including International Mobile Telephony - 2000 (IMT-2000), where multiple layers of cells will be used to provide an overflow capability.

One of the key features of IMT-2000 will be the provision of services via the satellite component to areas that are not covered by terrestrial networks. This feature will be ideally suited to countries with widespread regions of low population density, for which terrestrial cellular services are not economically viable. The satellite component will also provide a flexible resource capable of extending the capacity of the terrestrial component in critical load conditions, thus improving the quality of service. Co-operation between terrestrial and satellite environments will allow for flexible and optimised radio resource allocation and active user management strategies, ideally resulting in a reduction of service costs and in the optimal exploitation of the two environments.

However, there is a cost asociated with these provisions. IMT-2000 poses considerable challenges in relation to teletraffic modelling due to the type and pattern of user mobility, the diversity of radio propagation and fading effects, dynamic resource assignment, heterogenous traffic mix and the employment of a multi-layer cellular structure.

This paper briefly outlines the development of third generation systems based on first and second generation cellular systems as well as satellite-based mobile systems. An overview of IMT-2000 is then given covering development responsibilities, system capabilities and access methods. Key features are then described, including the integration of first and second generation systems; compatibility of services; type of service; quality of service; terminal type and use; spectrum utilisation; and system architecture. IMT-2000 services are briefly outlined, including those based on the fixed telecommunications network and those specific to mobile users.

The development of the International Telecommunications Union (ITU) Recommendations which define IMT-2000, required consideration of several factors including radio access, spectrum requirements, regulatory environments and network issues. These factors are discussed as an introduction to consideration of the key Recommendations which are briefly described. Description of the Recommendations concentrates on those that will have the greatest impact on current mobile communications research areas.

Finally, the current status of IMT-2000 is outlined with a description of the current state of the ITU and non-ITU activities associated with the system.

A Teletraffic Model of Third Generation Mobile Communication Systems

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Satellite and terrestrial cellular communication systems currently exist as two independent environments. In third generation systems these will complement each other and the cooperation between the two will allow for flexible and optimal radio resource allocation resulting in a reduction of some cost.

However, the success of third generation systems will largely be dependent on their ability to provide quality of service (QoS) improvement over existing first and second generation systems, global coverage and increased subscriber population.

The performance parameters such as probability of blocking, probability of handoff and probability of forced termination determine the QoS by developing a suitable model. The QoS parameters associated with third generation systems can be estimated and compared with those for the first and second generation systems to determine the QoS improvement.

The radio propagation path in macro cells is characterised by large scale and small scale fading. These are typically modelled using log-normal and Rayleigh distribution respectively. Though, these models are appropriate for first and second generation systems, experimental results indicate that it is no longer possible to identify the fast and slow fading processes associated with the radio propagation path when considering pico cells and micro cells. The propagation characteristics for these smaller cells are highly dependent on local topographies and differ considerably from location to location.

In a multi-layered third generation system which is over laid with pico cells, micro cells, macro cells and mega cells; the propagation characteristics are expected to impose stricter requirements in relation to handoff, channel assignment and cell grouping than for the current systems. It is therefore important that these issues be addressed when modelling the third generation systems.

This paper focuses on the problems associated with modelling the multi-layer cellular architecture and proposes a rudimentary simulation model to study the performance improvements associated with a multi-layer system.

The paper presents some preliminary results of the study to demonstrate that there are many benefits associated with the multi-layer cellular topology of third generation systems. The study shows that the provision of an overflow capability for new and handover calls can considerably improve the QoS parameters and thus increase the number of users which can be supported in a given area.

Adjacent Channel Power Ratio Simulation for Wireless LAN Power Amplifiers

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Adjacent channel power ratio(ACPR) is the linearity figure of merit for digital communication system. Some papers of ACPR analysis can be found for the cellular and PCS systems, but as yet few research paper has been published for the 2.4GHz wireless LAN standards. As it is well known, after a long and hard standardization period, the IEEE's 802.11 committee has released the final draft of its specifications. The standard encompasses wireless transmission using 2.4GHz RF or infrared energy. The RF carrier can use spread spectrum modulation of direct sequence or frequency hopping techniques.

The paper has analysed the wireless LAN system of direct sequence spread specrtum (DSSS) modulation and constructed simulation environment with envelope simulation techniques(i.e. the hybrid techniques of harmonic balance and time domain analysis methods). And to predict the ACPR performance of power amplifiers, 22Mbps spreaded stream modulated 2.4GHz source were developed referring to the standards. And, an amplifier has been designed to optimize ACPR with the DSSS signal input.

The measurement of the 3stage GaAs MESFET amplifier shows +25.7dBm output (which satisfies the design goal of 250mW power), 28.5dB gain and less than -41dBc second and -35dBc third harmonics at 1dB compression. The ACPR is less than -31dBr and -51.8dBr beyond 11MHz and 22MHz frequency range offset from carrier, which meets the wireless LAN standards of less than -30dBr and -50dBr.

The paper discusses the relationships between the measured and the simulated ACPR. For simulation, the power amplifier is represented in two ways; one is the circuit level with nonlinear GaAs MESFET model, and the other is measured AM-AM and AM-PM characteristics over input power sweeping from -15dBm to +5dBm. The simulated and the measured differences are less than 2.5dB over 11MHz to 22MHz offset from carrier with -10dBm to 0dBm input. The results will have useful applications for the amplifier ACPR simulation of wideband communication system.

High-Speed Transmission for Wireless Personal Communications

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The stringent requirements for the next generation high-speed wireless personal communication networks (PCNs) far exceed those of the current second generation PCNs, and can only be satisfied by employing a very flexible air interface. In particular, finding a viable method for minimizing intersymbol interference (ISI) caused by delay spread in high-speed wireless communications systems is an important problem and has currently received lots of interest. In this paper, we will describe the various techniques that are currently under investigation for the high-speed transmission of wireless data. Specifically, we will briefly describe the advantages and disadvantages of using spread-spectrum [1], multicarrier modulation [2], equalization, and smart antennas [3]. In particular, we will describe a recently developed technique, which we will refer to as multicode modulation, for the high-speed transmission of data in wireless personal communications [4]. In this technique, whose potential applications include variable and high peak transmission rates in wireless multimedia communications, the high-rate bit transmitted data is serial to parallel converted into low-rate bit streams in a similar fashion to multicarrier or multitone modulation. However, in contrast to the multicarrier method, here we propose to modulate each low-rate bit stream using direct-sequence spread-spectrum on a single carrier. It is demonstrated that by selecting the processing gain properly the total required bandwidth will be of the same order as the original high-rate data stream; thereby, gaining the inherent benefit of multipath rejection without expanding the bandwidth of the original high-rate stream. To demonstrate the potential and merits of the proposed method as an alternative technique for high-speed transmission for wireless personal communications, various simulation results over a multipath Rayleigh fading link are presented. Furthermore, we will show that by using interference cancellation as well as error control coding significant performance improvement can be achieved.

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Higher Order Statistics Based Multi-User Canceller for Electromagnetically Dense Communication Environments.

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With the ever increasing use of mobile telephones, the communication channels for mobile systems have become electromagnetically dense and very hostile. The channel capacity in such systems is governed by multi-user co-channel interference, whose elimination is crucial for system quality. However such interference rejection measures are not easy because the propagation environments in such systems are affected by low signal to noise conditions as well as being subject to strong multi-path and fading effects. Several interference cancellation schemes have been suggested [1]. The disadvantage with the majority of the existing interference cancellation methods is that they use purely second-order, Mean Square Error (MSE) based, statistics. Second order statistics are ideally suited to Gaussian signals but they can not deal with non-Gaussian channels, which exhibit strong non-linearities and correlated interferences (the latter is caused, in present multi-user cellular environments, by the highly correlated broad-band non-Gaussian signals [2]). Accordingly we propose a new technique, which employs Higher Order Statistics (HOS) based interference cancellation methods. The primary advantage of employing HOS is that they are capable of identifying phase information from the interference signals. The second advantage is that they are robust to Additive Gaussian Noise (AGN) and so the method is ideally suited to the study of non-linearities and correlated non-Gaussian signals

In the proposed technique, a new sub-optimal interference cancellation scheme employs an adaptive array antenna within a direct sequence spread spectrum multiple access air interface. In contrast to present approaches the proposed scheme exploits angular diversity at the array antenna in order to counteract highly correlated multi-path propagation effects. It is well known that the convergence speed of the Least Mean Square (LMS) algorithm, based on second order stochastics, is highly dependent on the eigenvalue spread of the covariance matrix, formed from multi-user input data. Adaptation of such a scheme, as an optimisation routine for Direction Of Arrival (DOA) estimation, gives incorrect results at the array antenna. In cases where eigenvalue spread is manageable, the routine converges very slowly when the Signal to Noise Ratio (SNR) is low. In order to eliminate these problems, we have developed a new stochastic gradient routine, using a covariance matrix which employs higher order cumulants .

The presentation will include the theoretical basis and structure of the proposed interference cancellation scheme, including the algorithmic developments. The use of the scheme in the present modern multi-user mobile radio environments will be illustrated, with relevant examples including Code Division Multiple Access (CDMA) air interface. These will be supported by simulated results, using realistic data for electromagnetically dense propagation channels subjected to strong multi-path effects and exhibiting low SNR conditions.

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Session M04
Wednesday, July 15, AM 08:40-11:40
Room R03
Near Field 3 : Field Measurements via the Modulated Scattering Technique (MST)
Workshop on Complex Media and Measurement Techniques

Organisers : J. Ch. Bolomey, F. Gardiol

Chair : F. Gardiol

Recent Developments in MST Techniques and Applications : a Review

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The Modulated Scattering Technique (MST) has been initially developped for achieving low-perturbation measurements of electromagnetic fields, especially in the vicinity of wire or aperture antennas. For this purpose, the signal to be measured is not delivered by the probe at its load, but re-radiated and received by the antenna under test itself (monostatic case) or by an auxiliary antenna (bistatic case). Consequently, the parasitic effect of the cable/guide connecting the probe to the receiver was suppressed, resulting in an increased accuracy and reliability of the measurement process. While the Non-Modulated Scattering Technique may exhibit some specific unique advantages, the modulation of the field scattered by the probe has provided a very significant improvement of the sensitivity and of the discrimination capabilities against parasitic non-modulated signals. This discrimination capability is crucial in modulated probe arrays and offers the unique advantage to avoid microwave multiplexers.

During the last decades, the research and development efforts have been successfully concentrated on two major topics. Firstly, very low-invasive probes have been used for mapping the field distribution in the close surrounding of printed circuits and components, or radiated by antennas, industrial and medical applicators, etc ... . Secondly, rapid and accurate near-field measurements by means of probe arrays have been used for the characterization and diagnostic of antennas or complex radiating systems for radar, telecommunications, EMC and RCS applications. While most of the efforts have been focused on technology, it is expected that some optimization of the performances could be still achieved via a more accurate modelling of the non-linear loading of the probes. Furthermore, if MST data have been mainly used for direct monitoring or for standard wave transformations, such as near-field to far-field transformations, more specific phase-less processing can be expected to enlarge the possible ways of using MST techniques.

This paper reports recent advances and expected trends of MST technologies and applications.

Separability Criteria for the Long-Wire Scattering Technique

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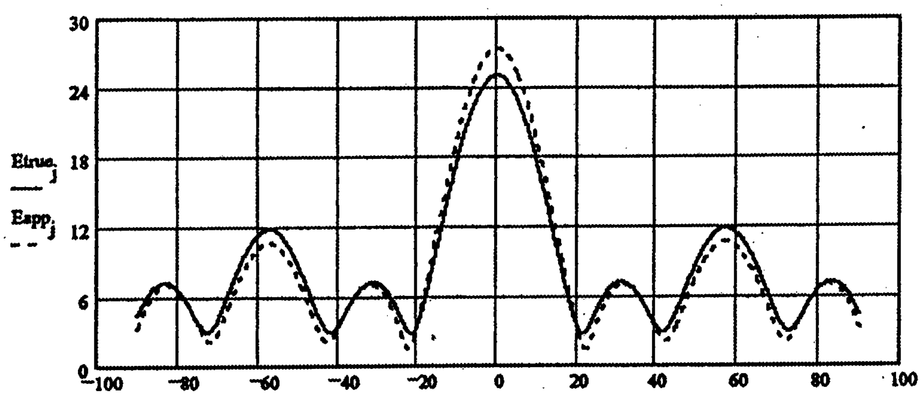
The long-wire scattering technique is a simple and rapid method for obtaining the H-plane radiation pattern of a linearly polarized antenna from near-field measurements. The long wire is arranged parallel to the electric vector, and the reflection coefficient at the input of the antenna is measured as the wire is moved across the aperture plane. The method is based on the reciprocity theorem and depends on the aperture distribution being separable. Under these conditions, it has been shown experimentally to give good results. However, the requirement of separability naturally leads one to ask how the method will perform when the distribution is not separable, or is only approximately separable.

To answer the first question, a circular aperture is considered, and it is shown that the results depend greatly on the aperture distribution. For a non-separable parabolic distribution the results are quite good, whereas for a uniform distribution, the result is not satisfactory.

For the second question, a rectangular aperture is considered. It is assumed that the nominal aperture distribution is separable, but that there are non-separable random errors int the element excitations. In this case, it is shown that for a uniform excitation the results from the long-wire method are remarkably accurate. A normal distribution of errors is assumed with a mean value of zero and with several different values of standard deviation. The results shown in the figure below show that the true and apparent radiation patterns compare well even with a standard deviation as high as 0.5.



Comparison of true and apparent radiation patterns with $\sigma = 0.5$

In the lecture a number of other examples will be given, together with some comparisons of radiation patterns as predicted by the long-wire method, and as measured on an antenna range.

The authors wish to acknowledge the valuable suggestions made by Sir David Davies, the originator of the long-wire technique.

Measurement of Near-Field Diffraction Patterns by an Optically Modulated Scatterer

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The optically modulated scatterer apparatus used monostatically at the National Physical Laboratory, Teddington, England is described by Dr Liang in another paper at this meeting. The present paper summarises how it has been used to measure several different kinds of near-field diffraction patterns, typically at a frequency of 10 GHz.

It was first used to measure the standing wave pattern set up in front of a conducting plane, to find out how close to the plane it could be used before unwanted interaction effects set in. The amplitude error in this extreme case of interaction was found to be less than 5% beyond a distance of $\lambda/6$. It was then tested on a field distribution that is already precisely known theoretically : namely the diffraction field formed when a plane wave is incident on an infinite conducting half-plane. All the expected fine detail of the pattern was faithfully reproduced. Encouraged by this result we then used the probe to measure a diffraction pattern about which there is some theoretical uncertainty : namely, the field due to a plane wave incident on a 'black' half-plane. Because of the fundamental difficulty of defining a black screen within electromagnetic theory, there is room for more than one theory of diffraction by a black screen. Our experiment gave results in front of a highly absorbing screen that do not agree with the standard Kirchhoff theory and show better agreement with the less familiar black screen theory due to Sommerfeld. (Behind the screen the predictions of both theories are virtually the same.)

Kirchhoff theory, in contrast to the Hannay-Sommerfeld theory, predicts 'superposition of apertures' : namely that the fields due to separate apertures in a black screen simply superpose. Experiments with two slits in a highly absorbing screen showed convincingly that superposition of apertures does not hold in that case, thus favouring the Hannay-Sommerfeld approach.

In addition to these experiments designed to test fundamental unresolved questions in diffraction theory, the optically modulated scatterer has been used to scan the near field of horn and other antennas (in order to infer the far field), and also to explore the field inside a horn. Used in this way, the method has confirmed basic assumptions about the near field made in a calculation, from first principles, of the far-field gain and directional pattern of pyramidal horn antennas, and the variation with frequency. Because it can scan only $\lambda/10$ from the aperture plane of a horn antenna, problems arising from truncation of the scanning area, although not negligible, are less serious than they would be with more conventional scanners.

A Field Mapping Technique With Minimum Intrusiveness : The Optically Modulated Scatterer

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After nearly 50 years of continuous development, the modulated scatterer technique has been developed to use an opto-electric switch to form the modulated scatterer. By using optical means to produce modulation, there is no longer a need to maintain an electrical link between the scatterer and the modulation source. In this way, the intrusiveness of the scatterer to the electromagnetic field is minimised. By using an optical fibre to guide an amplitude modulated infra-red laser beam on to an optomicrowave switch as a centre load of a small dipole scatterer, we have shown the optically modulated scatterer (OMS) to be a versatile tool for mapping RF & microwave field distributions, both in amplitude and phase, with minimum intrusiveness.

In order to overcome the multiple path problem with field mapping, a monostatic configuration was chosen to form the measurement system with the OMS. Phase continuity was used to overcome the problem of phase ambiguity caused by the fact that monostatic detection measures only the square of the field. By simulating the scattering field of a small loaded dipole scatterer under plane wave irradiation with NEC numerical simulation software, an analytical formula and the equivalent circuit were found to describe the behaviour of the scatterer. With this information, an optimised OMS has been designed and manufactured. The measured performance of this OMS was compared with other types of OMS. With this optimisation, the dynamic range of the field measured was extended from the original 23 dB up to better than 60 dB.

The measurement performance of the OMS field mapping system with a homodyne receiver has been investigated. This prototype system has been used intensively to investigate field distribution and propagation in the frequency range of 2 to 18 GHz. Two major problems, one linked with more than one scattering by the dipole and other nearby scattering bodies and the other linked with the performance of the dual channel homodyne receiver, have been identified. To correct the latter, a post-measurement data processing procedure was derived. To deal with the former, two OMSs with different scattering lengths can be used to extrapolate to the original field without measurement distortion.

This technique has been compared with the conventional near-field measurement technique and other field mapping and field sensing techniques. With its flexibility, simplicity and reliability, we believe that the OMS technique has much to offer in the future.

Diagnostic of Printed Antennas and Circuits

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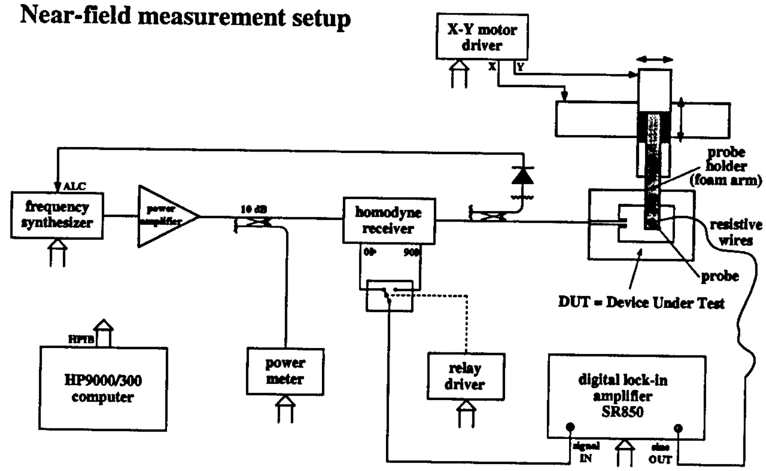
With today's modern instrumentation like Automatic Network Analyzers the measurement of most microwave circuit and component parameters is quite easy and very accurate. However, the understanding of physical phenomena like standing waves or the isolation of a hybrid junction would be easier if one could "see" the fields in the close vicinity of the circuit.

In the case of antennas, the far field pattern is generally measured in some particular planes. This limited information does not provide a direct understanding of what actually takes place within the structure. A close "view" of the fields could help a lot to diagnostic some problems which can happen within planar structures. For this purpose, a sophisticated measurement setup has been developped and will be presented, together with examples.

The measurement system uses the *modulated scatterer technique.* The probe used to explore the field doesn't carry any microwave signal, but contains a diode modulated by a low-frequency signal. This probe perturbates locally the fields and reflects a signal modulated at the low frequency. This signal comes back from the measured structure, and can be extracted from the steady-state reflected signal, which is non-modulated. A combination of a homodyne receiver and a lock-in amplifier yelds a very sensitive system. A schematic of the measurement setup is shown in the figure below. The actual system covers the 0.7 – 2 GHz and 2 – 8 GHz bands. An HP 9000 series computer controls all instrumentation and computes both amplitude and phase of the fields. A very user-friendly BASIC program has been written to automatize the measurements. For high quality color plots both in 2-D or 3-D, the data are transferred to a UNIX station and represented using a commercial software.

Near-field measurement setup



The system measures about 2 points per second,with a dynamic range greater than 40 dB. Various probes have been realized with low-cost miniature Schottky diodes. Direct modulation of the diodes through resistive wires is used. Probes for electric field (dipole type) and for magnetic field (loops) have been realized, all having dimensions between $\lambda/20$ and $\lambda/50$. All field components can be measured (E_x, E_y, E_z, H_x, H_y and H_z).

A lot of examples will be presented, both for microstrip circuits (various hybrids) and for microstrip antennas, showing the usefulness of this simple method to establish diagnostics, and also for didactic purposes.

New Application of Wlan-Concept Modulated Backscatter and Spread Spectrum Techniques

F. Völgyi, P. Olasz and I. Mojzes

The needs of modern automated computer controlled manufacturing make it necessary to apply such new concepts in measurement techniques, which were only used before in telecommunications. After a short overview of these the presentation describes in details a microwave measurement system developed by the authors, which is used for on-line, real-time monitoring of large sized composite boards. We describe the significant microwave components, give the electromagnetic model of the measurement problem – the linear interpretive model for measuring the moisture content of clipboards, as well as the permittivity model of four-phase mixture used for controlling the material structure (density, amount of glue, air inclusions). After showing laboratory measurement results, the presentation ends with a review of the many factory experiences.

A new concept is frequently used at microwave WLAN (Wireless Local Area Network) systems: these are passive terminal stations, acting as transponders in which no microwave power is generated, while there are fixed stations (FXS), where most of the active microwave functions are executed or transferred to a central station. At the passive terminal station, only a simple Schottky-diode is used, acting as a passive detector/backscatter (PDB), and using the modulated backscatter technology. Sometimes the ISM-frequency bands are used in industrial measurement systems. In order to comply with license-free operation, the FXS utilize direct sequence spread spectrum (DSSS) principle for the uplink and downlink communication with the PDBs, which have individual codes.

We have used these principles to create an electronic shelf label (ESL) system using microstrip antennas (MSAs) at [1], and realizing a permittivity monitoring system (PMS) at [2]. During the development of these systems we could well utilize the experiences we got in connection with microwave moisture sensors [3].

Conclusions

Using methods mentioned in the title, a free-space / reflection / double-transmission type microwave measurement system has been developed for monitoring of large-sized composite boards. This instrument shows considerable promise for on-line measurement of wood and plastic products. The results of industrial measurement series were well established with the given mathematical modells.

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Vector E Field Probe for ISM Applications

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Measurement is a crucial aspect in electromagnetic progress and inn development of microwave techniques. An equipments for measuring the electromagnetic field distribution in industrial applicators, powered by an ordinary magnetron, will be presented.

The probe consists of three orthogonal dipoles, which are modulated independently by three phototransistors. The amplitude and the phase of each electric field component are measured by analysing the scattered wave with two double balanced mixers operating in quadrature. The double balanced mixers work with a reference signal which is supplied directly by the magnetron although it emits a non monochromatic and pulsed wave. But, the modulation frequency is chosen equal to half of the magnetron pulse frequency. After recording and filtering the signals by a computer the amplitudes of the orthogonal components of the electric fields are evaluated with a 2% uncertainty and their phases are determinated to $\pm 5°$.

The design can be used for measuring intense electric fields up to 10 kV/m , the limit being governed by the level of the modulated light.

Advanced Modulated Scattering Techniques (A-MST) : a New Approach for Rapid Electromagnetic Field Measurements

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During the last decade, Satimo has developped and realized rapid measurement systems based on the use of the Modulated Scattering Technique (MST) [1],[2]. Such equipments are dedicated to different applications including antenna testing and EMC coupling assessments. More recently, the development of new generations of antennas and radiating systems requires always increased measurement performances, rapidity and flexibility in arranging the experimental setup. For such purposes, Satimo has designed and developped a new generation of probe array elements, based on the so-called Advanced Modulated Scattering Technique (A-MST) [3]. As compared to other existing MST configurations, A-MST probe arrays offer a more compact configuration integrating the radiating element iself, its modulator and the collector. Such a new configuration allows, typically, two octaves frequency range coverage, between 400 MHz and 18 GHz, with dynamic ranges larger than 70 dB. The measurement rate is about 5,000 points per second and is well balanced with the data acquisition rate of modern receivers devoted to antenna instrumentation. Consequently, by comparison with standard single probe measurements, the duration of the measurement process can be reduced by a factor 100 to 1,000.

This paper presents the preliminary results obtained with a A-MST demonstration model developped within the frame of a contract of the Ministery of Defense (DGA). The demonstration model is a 5.7 ft long linear array of 64 dual polarized probes covering the 1.5 GHz to 6 GHz frequency band. The performances of the demonstration model have been assessed with a test antenna consisting of a panel of the ERS-2 satellite, provided by the European Space Agency and the Ericsson Company. The panel, which operates in the C band, is constituted with slotted waveguides. Its dimensions are 1m by 1 m. Translating the A-MST demonstration model in a planar arrangement, 15 s are sufficient to acquire the near field data required to perform near-field to far-field transformations. Furthermore, near-field data are shown to provide interesting diagnostic capabilities via rapid spectral imaging of the feld at the surface of the panel. As a conclusion, the paper presents future projects involving the developement of A-MSTprobe arrays.

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