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Volume 3

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Progress In Electromagnetics Research Symposium

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Organised by
The Electromagnetics Academy
IRESTE, Université de Nantes
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Institut Universitaire de Technologie, Université de Paris X

PIERS 1998

Progress In Electromagnetics Research Symposium

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PIERS 1998

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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

Session A09
Friday, July 17, AM 08:40-10:40
Room 300
Scattering I
Chairs : D. Maystre

Near-field Scattering of a Ship in the Sea due to a Down-Looking Antenna

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The problem of electromagnetic wave scattering is very important in defense applications. The research on this topic was mostly centered on the target in free space, like the airplanes and missiles. If the target is a ship at sea, we have to consider the sea clutter and the interaction between the ship and the sea. There is no much public literature about the scattering of a ship at sea. What we can find first is a simplified formula by treating the ship as a point scatterer and take into account the multiple path effect due to the presence of the sea [1]. To use that formula, we have to place antenna in the far-field zone of the ship, consider only nearly-grazing incidence, and assume that the monostatic and bistatic far-field RCS are identical in all directions in the range of angles to be dealt with. In addition, we must determine the position of the point scatterer, which is very difficult. Another related work is Huang's Ph.D. thesis [2], which contains much useful information, and is the blue print of this study. Of course, if the ship is absent, there have been many studies on the sea clutter (for example, [2]-[4]), however, except in [2], we did not find convenient empirical formulas for bistatic scattering from the sea, which are important to our approach. The formulas in [2], which is adopted in our work, are relatively simple, but we are uncertain if these formulas can be applied to actual sea areas. Also, in Huang's work, the conventional UTD and inefficient ray-tracing are applied, thus his method can deal with only ship models composed of small number of regular shapes like elliptical cylinders, elliptical cones, and plates.

In my presentation, an algorithm will be introduced to calculate the near-field scattering of a ship in the sea due to a down-looking antenna. The effects of the sea surface, including the sea clutter and the ship-sea interaction, are considered. For the sea clutter we divide the illuminated sea surface into rectangular patches, and the contribution of each patch follows the model used in [2]. For the direct return from the ship and the interactions between the ship and the sea, we shoot and trace a lot of ray tubes. In each ray bounce we derive an equivalent image source, and accumulate the contributions of the first and the last bounces by physical optics integrals. Since in our approach the ship is composed of triangular facets, and efficient ray-tracing techniques are utilized, we can deal with ships of arbitrary shapes. Some numerical results will be presented to show good convergence. Especially, in one case where the point-scatterer model is applicable, our curve is close to the one obtained by the treating the target as a point target.

References

[1] N. Levanon, *Radar Principles* , New York: John Wiley & Sons, 1988.
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[3] M. I. Skolnik, Introduction to Radar Systems, New York: McGraw-Hill, 2nd ed. 1980.
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Scattering at a Rotating Cylinder

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The scattering pattern due to a moving body, illuminated by an incident wave, is influenced by its motion and it can be exploited to gain information on the properties and the state of motion of the body. In the past, much attention has been given to targets in translational motion with constant velocity. But the scattering pattern of rotating bodies can also be used to probe their structure: to analyse, for instance, the stability of plasma columns which plays an important role in astrophysics, or the confinement of nuclear plasmas, or still the spin velocity of satellites due to geomagnetism.

Unfortunately, all the previous works on rotating bodies, an exhaustive list can be found in [1], use a galilean description of rotations in wich the azimuthal velocity is $v_\phi = \Omega r$ with as consequence a breakdown of the relativistic covariance of Maxwell's equations: an umcomfortable situation leading in many cases to doubtful results. Recently [2], it was shown that the relativistic Trocheris-Takeno description of rotations in which $v_\phi = c \tan(\Omega r/c)$ restores the full covariance of electromagnetism. In this talk, we use this relativistic description
to analyse the diffraction pattern due to a circular rotating dielectric cylinder immersed in plane waves of the E and H-types.

Starting from the usual constitutive relations in the instantaneous inertial frame in which the cylinder is at rest , we first get the corresponding constitutive relations in the laboratory frame to be used with Maxwell's equations. Then, using a Fourier series expansion of the electromagnetic field, we solve Maxwell's equations inside the cylinder. This implies to get the
solution of a second order differential equation with variable coefficients which is not a simple
Bessel equation as it would be for a stationary cylinder. So, some approximations are needed
and the general solution depends on a set of unknown amplitudes $\{a_k\}$. Outside the cylinder the total field, incident and scattered, has also a Fourier series expansion with coefficients $\{b_k\}$. The boundary conditions at the surface of the cylinder provide the necessary relations to determine $\{a_k\}$ and $\{b_k\}$ that are used to obtain the analytic expressions of the internal and scattered field supplying finally the scattering pattern.
It is shown how rotation distorts this pattern.

References

[1] J.Van Bladel *Relativity and Engineering* Springer Verlag, Berlin, 1984.
[2] S.Kichenassamy and R.A.Krikorian, *J .Math .Phys* . 35, 5726, 1994.

Electromagnetic Magnus Effect

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In fluid mechanics, the Magnus effect is a phenomenon wherein a force acts on a rotating cylinder whose axis is perpendicular to the flow of fluid in which it is immersed. The force is perpendicular to both the fluid direction and the cylinder axis. Let us now assume that the fluid flow is replaced by an electromagnetic plane wave, we proved in the previous talk that the scattering pattern is distorted by rotation. This suggests [1] that the rotational motion could generate a similar force and indeed the effect has been confirmed by calculations [2] but unfortunately with a galilean description of rotations. In this talk, we use the relativistic Trocheris-Takeno description of rotations to analyse the electromagnetic Magnus effect due to a circular conducting rotating cylinder immersed in a plane wave of the E-type.

We first discuss the scattering of a plane wave at a rotating conducting circular cylinder which is a more difficult problem than for a dielectric cylinder although the same techniques are availaible in both cases. Essentially to get the electromagnetic field inside the cylinder, we introduce the constitutive relations (expressed in the laboratory frame) in Maxwell's equations and we look for the solution in terms of a Fourier series. This implies a second order differential equation with variable coefficients much more intricate than for a dielectric. So, some drastic approximations are needed and to get tractable expressions, we assume a high frequency incident field and a small angular velocity. Then, for the inside field we get a general solution depending of the coefficients $\{a_k\}$. The scattered field outside the cylinder has also a Fourier series expansion with coefficients $\{b_k\}$. The boundary conditions on the surface of the cylinder provide the necessary conditions to determine $\{a_k\}$ and $\{b_k\}$. We use the amplitudes $\{b_k\}$ to calculate the scattered field.

We may now analyse the Magnus effect. Since the time-averaged total force on the cylinder can be derived from Maxwell's tensor force [2], we start by giving the general form $< F >$ of this force in terms of the components of the total (incident and reflected) electromagnetic field outside the cylinder. Then, we substitute into $< F >$ the expressions previouly obtained for the total field. One checks easily that the Magnus force is zero for a stationary cylinder and for a perfectly conducting rotating cylinder. We give the expressions of the Magnus force for a cylinder rotating with a small angular velocity and in terms of skin depth for a very good conducting cylinder.

References

[1] B.M.Bolotovskii and S.N.Stolyarov *JETP Lett*. 25, 135, 1977.
[2] D.De Zutter *Appl .Sci .Res* .41, 17, 1984.

The Delta Boundary Operator (DBO) Approach to Electromagnetic Scattering

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High frequency methods such as Physical Optics (PO), supplemented by a form of the Physical Theory of Diffraction, can often be successfully applied to large scatterers. However, inaccuracies can occur and these can usually be attributed to the neglect of surface curvature or to the implicit assumption that the scattering is essentially a local phenomenon. Common non-local scattering mechanisms which can contribute significantly include creeping waves and travelling waves.

The Delta Boundary Operator (DBO) technique[1,2] is an alternative formulation of electromagnetic scattering which offers a natural framework to account for surface curvature and non-local effects and thus may provide a basis for more accurate predictions of scattering by electrically large bodies. The original method has been extended by the present author to enable treatment of scattering by doubly-curved bodies. Approximations based on a physical understanding of the scattering process have been introduced to simplify the formulation and hence reduce the required computation. The resulting scheme shows that the surface current at any point is most strongly influenced by the shape of the scatterer in the immediate neighbourhood in an 'upwind' direction as determined by the propagation vector of the incident wave. Alternatively, the scheme may be viewed as modelling current flow over the scatterer in the 'downwind' direction, thus providing a physically appealing picture. A treatment of edge diffraction has also been incorporated.

The new technique has been implemented for some simple problems by adopting flat-facetted geometry models of the scatterers. The predicted surface currents vary smoothly through the shadow boundary and are almost always more accurate than those given by PO. The computation time increases as the cube of the frequency which, although comparing unfavourably with the frequency squared dependence of PO, is the lowest order dependence to be expected for any technique which aims to treat creeping waves and other non-local scattering phenomena in a physically realistic way.

In this presentation the principles of the DBO approach will be described and its potential for improving the accuracy of high frequency scattering predictions will be demonstrated.

References

[1] D.Maystre; 'Electromagnetic scattering from perfectly conducting rough surfaces in the resonance region', IEEE Trans. Antennas Propagat., vol.31, 1983, pp.885-895.

[2] D.Maystre; 'A rigorous theory for problems of scattering: the Delta Boundary Operator method', J. Mod. Optics, vol.34, 1987, pp.1433-1450.

Modified Physical Optics Approach for Line Current Wave Scattering by Coated Planar Strips

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Electromagnetic scattering from compound metal-dielectric obstacles arises in many physical contexts and its analysis is therefore of interest from both theoretical and practical points of view. Planar and curved metal-backed dielectric surfaces have been considered for modeling composite and radar absorbing materials developing the concept of approximate boundary conditions. However, in the analysis of scattering by finite coated perfectly conducting strips there still exist some difficulties in the efficient numerical implementation of the solutions. Because of the complexity of scattering process, the method of moments and other numerical techniques become computationally intensive and often unsuitable especially to electrically large coated surfaces. In this paper, we present the modified Physical Optics (PO) approach to effectively solve the problems of line current wave scattering from finite planar metal-backed dielectric strips.

As is well-known, classical PO method was formulated for calculating the field scattered by perfectly conducting surfaces and proved to be widely used in reflector antenna design. This work is a further development of the numerical PO approach to analyze the 2-dimensional wave diffraction from planar strips coated with a homogeneous dielectric layer. The cases of both electric and magnetic line current wave incidence corresponding to E- and H-polarization have been considered. At first, we introduce the equivalent electric and magnetic PO currents on the dielectric interface by using the expressions of exact reflection coefficients of an infinite grounded dielectric slab under the plane wave incidence. Taking into account the later assumption, in practical calculations the line source should be at least a wavelength away from the dielectric surface. The reflection coefficients, and therefore the derived equivalent PO currents, depend on slab's thickness and permittivity so that the present analysis allows a quantification of the effect of a coatings on the scattering properties of the strips. Next, to calculate the scattered field we integrate these currents over the actual width of coated strip performing integration along the dielectric interface. The obtained full field patterns are compared with those of perfectly conducting strips of the same width calculated by conventional PO numerical integration. It is shown that the presence of a coating not only affects the amplitude levels but due to multiple reflection shifts the scattering lobes orientation. Numerical results have been obtained for different thicknesses and wide range of the scatterer's width, dielectric permittivities, and the line current positions demonstrating that one can substantially change the scattering properties of a coated strip by varying its geometrical and material parameters. One particular limitation of PO approximation has been discussed in modeling the scattering by finite planar strips under grazing wave incidence, especially for the E-polarization of electric line excitation when PO solution erroneously gives no scattered field though it correctly predicts zero field scattered by a very thin coated strip under H-polarized magnetic line current lying in the plane of a scattering surface.

In the case of thin multiple dielectric coatings, the reflection coefficients of a multilayered grounded dielectric slab should be used in defining the equivalent currents on the upper dielectric interface in order to calculate the radiation integrals.

The robustness of proposed approach can also be exploited in calculating scattering patterns of smoothly curved coated strips provided that the radius of curvature is large enough so that the obtained equivalent currents are being integrated over the actual surface of a compound scatterer.

Session A10
Friday, July 17, AM 10:40-12:40
Room 300
Structure Complex
Chairs : M. F. Wong

Multi-Layer Coatings with Random Optical Thickness

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Optical structures composed of multiple layers serve as mirrors, windows, beam splitters, and filters, with varying frequency characteristics. The individual layers are a fraction of a wavelength in thickness. The design of such a system specifies the optical thickness of each of the layers, i.e. their index of refraction (or equivalently their dielectric constant) and their geometric thickness. Typical designs can contain scores or hundreds of layers.

The present work describes analytical methods for determining the statistical departures of the transmittance and reflectance from their ideal design values, due to random errors in optical thickness of the different layers.

The characteristics of a specific structure are given by a matrix product, each component matrix being a function of the optical thickness of its corresponding layer. The overall matrix product yields the incident and reflected waves at the input, corresponding to a unit output. The desired results are the transmittance and reflectance of the entire structure. The transmittance is equal to the reciprocal of the input, and the reflectance is equal to the ratio of reflected to incident waves at the input, for unit output. The transmittance and reflectance are readily calculated from the incident and reflected wave complex amplitudes in the deterministic case, i.e. the ideal structure with zero errors from the design values for optical thickness of the different layers.

Kronecker product methods yield the statistics of the incident and reflected input waves for random layer parameters. However, the transmittance and reflectance statistics are not directly related to these input statistics. We exploit the fact that the performance of useful devices must not depart significantly from that of the ideal device. Combining Kronecker products with perturbation theory yields the desired transmittance and reflectance statistics.

Useful results include average values, average powers, power fluctuations, and gain-frequency statistics of the transmittance and reflectance for various multi-layer optical devices, as a function of their layer tolerances.

Optical Response of Multilayer Surface Relief Bigratings with Non-Identical faces

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A new approach is proposed for analysis of scattering by surface relief bigratings with non-identical faces. An example of the elementary cell of such a structure is given in Fig.1 The method combines the simultaneous use of several different coordinate systems and the generalized S matrix formalism.

The scattering of doubly periodic or crossed gratings has been the subject of many studies. Rigorous methods for 2D-diffraction gratings include finite-difference method, the method of variation of boundaries , the Rigorous Coupled Wave Analysis and the curvilinear coordinate methods among which the Chandezon method is the most popular because of its numerical simplicity. The basic features of this last method lies in the use of a coordinate system such that the layer interfaces become coordinate surfaces thus facilitating the expression of the boundary conditions. Since the new system is non-orthogonal, a formal tensor approach is advisable. The field is decomposed into transverse electric (TEy) and transverse magnetic (TMy) vector fields. These are defined in the same way as is usual in the theory of waveguides with the direction orthogonal to the interface medium plane being the preferred direction. We derive the TEy and TMy field from the solution of a single scalar eigenvalue equation. This formalism is easily extended to parallel corrugated layers, such as dielectric-coated bigratings. These structures represent a generalization of the theory of planar stratified media.

We apply this formalism to layers with non-parallel faces, the only restriction being that they have the same period. This requires the simultaneous use of several different coordinate systems and the translation of the solutions from one system to solutions in another system. The modeling presented here can be applied to the exploration of the optical response of three-diemensional photonic solids.

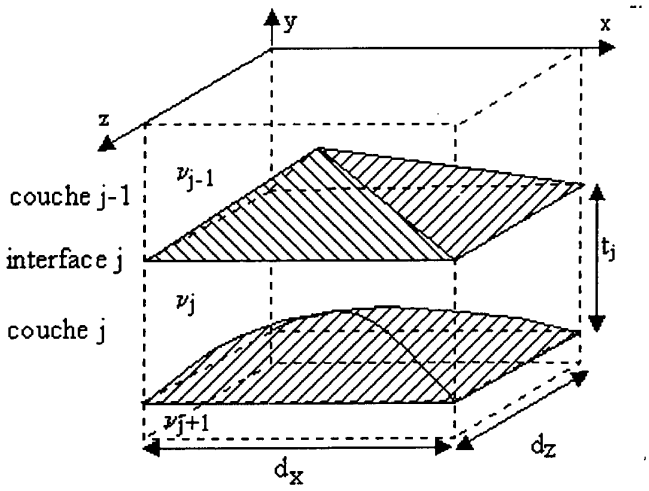

Figure 1

Symmetry of the Field Transmitted by Bi-Periodic Metallic Grids

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The symmetry properties of the diffracted orders of gratings in the resonance domain are frequently used in diffractive optics [1]. For example, a beam-splitter element or star coupler (fan-out to N) is obtained with a grating that produces N equal-efficiencies diffraction orders. In general, those gratings are synthetized by using a parametric optimization algorithm combined to rigorous electromagnetic theory. Their shape is then precisely defined. However, in certain cases, the identity of the transmitted efficiencies stems from simple considerations on the symmetry of the field at the bottom of the grid and it does not require drastic specifications on the motif of the grating. In [2] we have pointed out that lamellar metallic gratings produce two symmetric transmitted orders if they are illuminated under –1 Littrow mounting and if the width a of the groove satisfies $l/2<a<l$ in s polarization and $a<l/2$ in p polarization, (where l is the wavelength of the incident beam). This is due to the domination of the symmetric propagative fundamental mode of the through-holes at the bottom of the grating. We have extended this analysis to bi-periodic grids. We show that, under certain conditions on the size of the rectangular through-holes, a perfectly conducting grid produces 4 equal intensity transmitted orders if it is illuminated under (-1,-1) Littrow mounting. We also give a simple analytical expression of the transmitted near field that allows us to calculate the distribution of the electric intensity below the grid. This last point is important if the grid is to be used as a mask in the framework of high-frequency grating duplication by 'photomask self-interference' technique [3].

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The magnetic field formulation applied on 2D axe-symmetrical magneto-dynamics problems with physical properties complexes

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There are a lot of mathematics formulations to solve magneto-dynamics problems by the Finite Element Method (FEM), but when a problem where dielectric properties of the material have a great importance, a formulation that admits the utilisation of the two physical properties (magnetic and dielectric) are necessary.

In the 2D axe-symmetrical magnetic field formulation (**H** formulation), the value of the magnetic field are used directly as boundary conditions. The physical properties of the material used are complexes and they have been founded by a specific characterisation method, using the two assistance measures of the impedance complementary.

The 2D axe-symmetrical formulation is applied on a core of linear, isotropic and homogeneous magnetic material. This core is submitted to the magnetic excitation $\mathbf{H}_0$ of a superficial current I. The core is unfolded and equivalent to a blade of parallel faces of equal length with respect to the average core perimeter. The electric and magnetic fields are supposed to vary only following the alone direction x (radial).
The system may be resolve through :

$$\frac{1}{r}\mathrm{rot}\left(\left(\frac{1}{\sigma + j\,\omega\,\varepsilon_0\varepsilon_r'}\right)\mathrm{rot}\,rH\right) + j\,\omega\,\bar{\mu}\,rH = 0 \qquad (1)$$

The objective of this study is to connect fields **H** and **E** (inside the core), to complex physical properties of the material ($\bar{\mu}$ et $\bar{\varepsilon}$), with respect to the dimensions and the excitation $\mathbf{H}_0$. The validation of a simple analytical model is desired to solve magneto-dynamics problems associated with a real core. This validation will be made by comparing values of magnetic impedance calculated by the FEM, with analytical values.

For this case, a model axe-symmetrical is used and the magnetic field (boundary condiction) is applied in all tour of the model . The field applies is given for the relationship :

$$H_T = H \cdot radius = \frac{nI}{2\pi} \qquad (2)$$

n = numbers of the spires , I = electrical current (A), and outside of the model, in the air, the field is considered zero.

The magnetic impedance ZB (2) of the device is a function of the magnetic flux through a section of the core, and is given by :

$$ZB = j\omega\,\frac{\Phi}{I} \qquad (3)$$

A comparison with data calculated from the analytical model (3), allows the validity of the mathematical formulation and the hypotheses to be assumed .

$$ZB = 2j\,\frac{\ell}{b}\sqrt{\frac{\bar{\mu}}{\bar{\varepsilon}}}\tan\left(\omega\,\sqrt{\mu\,\varepsilon}\,\frac{a}{2}\right) \qquad (4)$$

These developments have been formalised for the purpose of replying to the need of possessing a precise analytical model capable to faithfully representing the complete magnetic characteristic of a magnetic material on a large frequency band. This method might to be used, for example, in a new method of ferrite material characterisation.

An Efficient Method for Synthesizing Dielectric Structures Including Two Frequency Selective Surfaces

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The study of dielectric structures including frequency selective surfaces is of great interest in several industrial applications. Among these latter, we can denote : sub-reflector for multi-band antenna, stealth radomes or electromagnetic shielding. The purpose of this paper is to describe an efficient method for synthesizing such structures, which allows to shorten in a great extent the conception cycle.

The methods usually used in order to analyze dielectric structures including several dichroïc structures are based on the use of so called "generalized [S] matrix". This technique needs to subdivide the structure into simpler sub-structures which are analyzed separately. The "generalized [S] matrix" is calculated for each sub-structure by evaluating its response when excited by plane waves propagating in directions corresponding to those defined by Floquet modes. The response of the whole structure is then obtained by "cascading" the [S] matrixes. The method presented here is not based on such a technique. The goal pursued is to obtain a method for synthesizing dichroïc structures, which needs a particularly efficient analysis technique. The "generalized [S] matrix" method was not found convenient for such a method.

The analysis technique used here is based on a global approach of the problem. It is limited to dielectric structures including two dichroïc surfaces of equal periodicities. Coupled integral equations are established according to the structure topology. They are expressed in the spectral domain, and discretized according to the Floquet modes. These equations are solved using method of moments in order to evaluate currents existing on the dichroïc surfaces. The elementary patterns of each dichroïc surface are subdivided in rooftop basis functions which can be dissymmetrical. The dielectric structure, which can be multilayered, is taken in account by its GREEN function. The code thus obtained is of a great accuracy and of a great efficiency. It is the core of the synthesis method.

The synthesis is obtained by using the aforementioned code in order to evaluate a cost function to be minimized. This cost function can be different radioelectrical quantities, depending on the purpose requested for the dichroïc structure. In the case of a radome, it could be the reflection coefficient of the structure in one or both polarization (TE or TM). The minimization of the cost function is obtained by varying structure parameters such as : dielectric constants, thickness of each dielectric layer, topology of elementary pattern, periodicities of the structure. The variation of each parameter is limited to certain extent in order to obtain realistic structures. The modification of the elementary pattern topology needed to develop automatic meshing procedures which insure current continuity in the new topology.

The accuracy and efficiency of this synthesis method have been demonstrated by the realization and test of dichroïc structures. Excellent correlation between simulation and measurement are obtained after a one step conception cycle, in spite of the great number of parameters influencing the structure response, making this method a most valuable design tool.

The Problens of Mathematical Simulation of Anisotropic Waveguides and Resonators of Microwave and EHF Ranges.

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1. The problem under investigation. The fields of application. Designing and Technical realization of superfast information processing systems (SIPS) functioning directly at radio frequencies in microwave, EHF and much shorter wave ranges for space-time processing of signals are only possible on three-dimensional integral circuits (TDICs) [1-6]. However, the structures oriented primarily on using electromagnetic waves (EMW) and permitting on TDICs to decrease mass-dimensional parameters of microwave - EHF module of SIPS by 1-3 orders and fast-action-by 1-2 orders do not entirely satisfy perspective technique and its designers. Simultaneous using of YDICs and basic elements (BE) in them on EMW and magnitostatic waves (MSW) can provide an essential gain in mass-dimensional parameters and fast action.

2. The fundamental principles of TDICs are: the principle of constructional confirmation and the principle of optimally of BE. TDICs have enabled to solve the well-known in micro electronics « problems of conductors radically [1,2,6]. The examples of diagram-forming matrices, filters for space time processing of signals and other BE on the basis of simultaneous using of EMW and MSW are given.

3. Maxwell's equation. Impedance anisotropic boundary conditions. System of Maxwell's equations in the form of [4]. In many cases its solution is greatly simplified by introducing impedance anisotropic boundary conditions [2,4]. The examples are: diffraction of EMW on an anisotropic semi planes, reflection from the surface with alternating anisotropic strips.

4. Generalized Fresuel's formulas. Models of semi infinite structures in the theory of EMW and MSW diffraction on anisotropic obstacles. Transition to inhomogeneous structures. Method of geometrical optics. Method of physical theory of diffraction. Method of WKB.

5. Film waveguide. The key structure allows rigorous solution. Wiener-Hopf-Fock method. Power dividers within « a floor » of TDICs and into different « floors » of TDICs. Conductor width jump, resistor, tail.

6. Impedance symmetrical slot line (ISSL). Mathematical model. Method of singular integral equations. Analytical solutions for anisotropic wall (substrate).

7. Solitons in SIPS. Definition. Necessary conditions of existing soliton in a wave guide with anisotropic and nonlinear films and layers. Two-sided boundary conditions. Analytical solutions. Evaluation of prospects for soliton application in SIPS on TDICs in microwave and EHF ranges.

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Session B08
Friday, July 17, AM 8:40-12:00
Room G/H
Electromagnetic Imaging for Biomedical Applications

Organisers : Ch. Pichot, S. Caorsi
Chairs : S. Caorsi, J. Ch Bolomey

Forward Solution Match Issues Affecting Iterative Inverse Scattering Approaches

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Electromagnetic inverse scattering techniques, especially in biomedical areas, are seeing broader application with the availability of increased computational power. In terms of the computational aspects of the problems, investigations have included back projection methods, pseudo-inverse techniques and iterative approaches. Within the narrower topic of iterative approaches, there has been considerable concentration in developing matrix regularization concepts specifically designed for guiding solution convergence closer to the desired solution without locking in to non-optimal paths. Alternatively, the work described herein focuses on techniques of improving the match between the numerical forward solution and the actual measured data. This issue is clearly important as it defines the final limits of the reconstructed image accuracy. The first topic discussed will be the choice of illuminating antennas. While conventional radar techniques generally employ plane wave illuminations in their associated models because the transmitters are many wavelengths from the target, this is not a suitable approximation for biomedical applications given that the transmitters and receivers must be electronically close to the target due to high signal attenuation when propagating through tissue. Our numerical approach produces accurate radiation patterns for various 2D antenna configurations given that suitable boundary conditions for each can be established. This is accomplished efficiently by discretizing only the boundary of each antenna through the use of the boundary element method and coupling the result with a finite element representation of the target region to produce an overall accurate electromagnetic solution. To illustrate the flexibility and strength of this approach, results will compare measurement data and the numerical forward solutions with both waveguide and monopole transmitters. Comparisons will include cases for a homogeneous medium and a variety of inhomogeneous target regions.

Additionally, because of the requirement of electronically selecting the transmit and receive antennas for rapid data acquisition, the presence of the full array of antennas causes significant field perturbations that eventually degrade the desired reconstructed images. We discuss numerical techniques for taking these extra antennas into account and, consequently, how this impacts the system hardware design. It should be noted that this compensation is accomplished efficiently within the context of the existing numerical model. We also show the imaging results from a system where the circular array has been reduced from 32 to 16 antennas to reduce the total number of extra antennas perturbing the field patterns. Here the reduction in measurement data is compensated for by rotating the array slightly to produce the extra illumination/receiver data sets. These results provide benchmarks for the best achievable images given the degree to which the forward solution approaches the observations.

Inverse Scattering Approaches for Electromagnetic Hazard Prediction

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Growing concern about the health effects of electromagnetic fields has motivated much effort to evaluate and understand the power absorption in the human head when exposed to hand-held telephone. The knowledge of the induced electromagnetic field distributions is necessary to quantify the power deposition in the biological tissues. Theoretically, this information can be achieved by means of numerical simulations, starting by the knowledge both of the electromagnetic fields produced by the source and of the complex dielectric permittivities of the biological system. In real cases, some informations are not completely available. On the other hand, it is possible to give an estimate of the electromagnetic fields by using realistic anatomically based models of the human head.

In this scenario, the microwave imaging techniques seem to be able to give useful informations as for the real situations (human-head and hand-held telephone) as for the test cases (phantom and hand-held telephone). In this contribution, we explore the possibility to use inverse scattering approaches to evaluate the health hazards during a mobile communication by means of a personal communication handset. In this way, we can deduce as the power absorption in the head-phantom model (i.e., when the dielectric characteristics are well-known), as the electric field distributions and the dielectric permittivity profiles inside the biological body, in a real case, by measuring only the scatterd electric field outside the head.

Preliminary results are provided concerning a two-dimensional case, in which the human head, illuminated by a short dipole placed near the biological tissue, has been modeled with a high-resolution head-image with detailed tissue distributions, obtained by the X-rays technique. They indicate the capabilities and the powerful of the proposed approach.

Precise Microwave Imaging for the Quantitative Assessment of Biological Tissues

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Recent development of a 2-D near field microwave imaging technique has shown certain potential for biomedical applications. Specifically, the non-invasive evaluation of dielectric constitutive property distribution and the inference of temperature from these temperature dependent constitutive properties are particularly attractive for *in-vivo* monitoring during hyperthermia treatments for cancer.

The developed system is based upon combining a high fidelity, heterodyne data acquisition technique with a hybrid element based iterative image reconstruction technique. Illumination frequency varies from 300 MHz to 1100 MHz. The use of this spectrum exploits the spectral dielectric characteristics of different biological materials. Fixed circular array transceivers of 16 and 32 equally spaced monopole antennas allowing for variable illumination area (minimum 14 cm diameter) have been studied. The antennas are empirically matched (better than -12 dB return loss) and embedded in biologically simulate media for improved signal coupling to the targets. Vector electric field measurements are electronically scanned around the array to recover the scattered signals.

Image reconstruction is achieved by applying Newton's iterative scheme on a dual meshed, hybrid element method which solves a forward 2-D near field scattering problem at each iteration.

The robustness of the imaging system under various experimental conditions are evaluated and presented. While a fraction of a degree in temperature sensitivity and centimeter scale spatial resolution have been previously recorded under special cases for discrete illumination frequencies and select biological phantom targets, it has now been observed that overall system performance continues to improve through enhancement in the fidelity of the data acquisition system and refinement of the image reconstruction algorithm. Details of these systematic improvements are presented and discussed. Emphasis will be placed on the importance of improving the overall system signal to noise ratio and accurate numerical modeling of the transceiver configuration.

Inversion Methods in Chirp Radar-Type Microwave Computed Tomography

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The spatial distribution of temperature inside a human body can be estimated by means of microwave computed tomography (CT) based on the following principles (M. Miyakawa, 1990, Proc. 3rd Asia-Pacific Microwave Conf., 841-844): a chirp pulse signal between 1 and 2 GHz is radiated from the transmitting antenna through the body and detected by the receiving antenna, placed on the opposite side of the body; by spectral analysis of the beat signal between the incident and transmitted wave, the signal transmitted along a straight line between the two antennas can be discriminated from multipath signals. By moving the system of the two antennas,a tomogram of the unknown temperature distribution can be obtained. Finally the unknown temperature distribution can be restored using standard algorithms of X-ray computed tomography.

The feasibility of the method has been demonstrated using cylindrical phantoms placed in a bolus of saline solution (M. Miyakawa, 1993, Med. & Biol. Eng. & Comput., 31, 531-536). However, an analysis of the tomograms indicate that they are still affected by a considerable blur which is mainly due to residual diffraction effects.

In order to improve the quality of the tomograms, and therefore the quality of the restored temperature distribution, we propose a processing of the tomograms based on a suitable deconvolution method. Since the blur is not known, this problem is essentially a blind-deconvolution problem.

We propose an iterative method, based on the so-called projected Landweber method for the solution of linear inverse problems, which is initialized by the blur obtained from the tomogram of a cylindrical phantom. The convergence of the method is rather fast and the improvement obtainable by means of this method is demonstrated in the case of cylindrical phantoms with different sizes and positions.

Two–Dimensional Profile Reconstruction of Biological Objects Based on Non-Linear Optimization

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A novel method for profile reconstruction of biological objects is presented. The method is based on the description of the unknown scatterer in terms of Gaussian basis functions with unknown coefficients and the discretization of the scattering integral equation (SIE) by applying a Gauss quadrature integration procedure. The inverse scattering problem is formulated as a non-linear optimization problem whereas the simultaneous solution of two sets of integral equations is imposed. The first set relates the unknown object function with the total wavefield inside the scatterer, while the second consists of the well known equation for the scattering amplitude and relates the object function and the internal field with the scattered field measurements at various detector locations. Ôhe proposed method can be applied to acoustic as well as to electromagnetic waves, provided for the latter case that the incident wave is pure TE or TM. Since the proposed method is not based on a perturbation approximation, it is not restricted to weak scattering and can be applied even for large size objects.

The resulting algorithm was implemented on the distributed memory Intel Paragon XP/S platform with 48 nodes, resulting in a considerable reduction of computational time. Inversion of cylinders of circular cross section (homogeneous or layered) from analytically exact data is used to validate the accuracy of the method. The convergence of the inversion algorithm depends on the initial guess of the scattering object. Therefore, special emphasis is given on the selection of an appropriate starting estimation for the coefficients of the Gaussian expansion of the scatterer.

Furthermore, the developed algorithm is evaluated by using data collected from a high precision ultrasonic measurement device. The experimental setup consists of a water tank in which the transmitting and receiving transducers along with the scattering object are immersed. The central frequency is chosen to be 3.6 MHz that results in wavelength of λ=0.4 mm at 20^{O}C. The receiving transducer consists of a needle hydrophone that moves on a straight line perpendicular to the propagation direction of the incident field. This linear scanning is performed by means of a stepping motor and controlled by a computer. The scattering object can rotate about an axis normal to the scanning line's plane, using a stepping motor, in order to achieve different angles of illumination. A stable sine wave generator produces a signal that passes through the power amplifier before feeding the transmitting transducer. The signal detected by the hydrophone is amplified and then quadrature demodulated where the real and imaginary parts are obtained and collected by a personal computer. This information is fed off-line to Intel Paragon XP/S computer where the reconstruction method is implemented.

Parallelisation of a Newton-Kantorovich Reconstruction Algorithm for Microwave Tomography

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The recent developments in microwave imaging have shown the capability of the new reconstruction algorithms to provide the user with quantitative images, in exchange for a higher computational cost. One of this new algorithms is the Newton-Kantorovich technique (NKT) that iteratively minimizes the error between the measured field scattered by the body and the scattered field calculated from a numerical model [1]. The procedure, starting with an initial distribution of contrast, successively computes at each iteration the *direct problem* by using the present reconstructed contrast map, and inverts a large ill-conditioned matrix, *inverse problem*, in order to update the contrast from the error between computed and measured scattered fields. This technique has allowed to obtain good results with both numerical and experimental data [2], but the reconstruction times are in the order of hours for large bodies in a CONVEX 3480 computer with a vectorial code.

The computational cost of the algorithm is extremely high, both in time, at each iteration the direct problem for each view has to be solved, and memory requirements, due to the large matrix that relates the contrast update with the error on the scattered fields. The usage of high performance parallel computers, like the SGI Origin 2000 with 64 processors placed at CEPBA (Barcelona, Spain), allows to reduce the reconstruction computational times by using parallel code. A «coarse grain» parallelisation has been chosen for the direct problem, the computation of the different incidences is splitted among the available processors. On the contrary, the inverse problem is optimized with a «fine grain» parallelisation, the inversion of the matrix is computed by using different processors. The parallelisation of the code is currently in progress and it is expected to reduce the reconstruction time for large biological bodies with the inverse NKT algorithms to less than one hour.

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Microwave Tomography for Physiological Imaging of Myocardial Ischemia and Infarction

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Various tomographic systems, such as nuclear magnetic resonance (NMR), X-ray and positron emission are widely used in medicine. Microwave tomography is a new modality potentially applicable to medicine. Although the expected spatial resolution of microwave tomography is not competitive with X-ray and NMR tomography, it may provide unique insights into the physiology and function state of the images structures in the human body. The purpose of this presentation is to 1) present the evidence for the influence of ischemia and infarction on the dielectric properties of the myocardium, 2) present our theoretical and experimental two-dimensional (2D) microwave image reconstructions from low to high contrast cases, including full-scale (human torso) high dielectrical contrast model and live biological objects, 3) present our three dimensional (3D) microwave image reconstructions of mathematical models and experimental phantoms.

It has been demonstrated that acute and chronic infarction (30 canines) causes significant changes in the dielectrical properties (up to 10-15%) which are considered to be enough for tomographic detection. The time course and magnitude of the changes paralleled the known physiological events accompanying ischemia, including an ion and water tissue alteration.

We have constructed two experimental tomographic systems with an operating frequency of 2.4GHz. The first was a 2D tomograph consisting of 32 emitters and 32 receivers with an acquisition time of 500 msec. The second was a 3D tomograph consisting of 32 emitters and 2 receivers that rotate and move under robotic control. We have developed various mathematical approaches to solve the inverse MWT problem. These include iteration schemes based on the Born and Rytov approximations, Newton and gradient method in 2D case. We used a vector Born generalized algorithm and Newton method for 3D reconstruction.

Successful 2D image reconstruction was achieved for a full scale mathematical high contrast model of a human torso which included a heart with areas of myocardial infarction (1cm). Images were also successfully reconstructed for 2D physical phantoms with varying dielectric contrast. Finally, in the 2D case, we reconstructed systolic and diastolic images of a beating canine heart. In 3D microwave tomography we have achieved results in reconstructing of mathematical and physical models in low-contrast case. Our approach has also been tested on biological objects.

Having the results of the successful model and experimental imaging and the understanding of the differentiation of myocardial infarction based on the dielectrical properties contrast, we conclude that microwave tomography is applicable for a physiological imaging of myocardial ischemia and infarction. Practical physiologic 3D microwave imaging will require further progress in the areas of system design, images reconstruction and tissue dielectric properties probing.

Optimization of the Dynamic Imaging Performances of a 2.45 GHz Planar Microwave Camera

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Dynamic imaging capabilities is often of prime importance in many medical and industrial applications. From this point of view, microwave imaging techniques suffer from some disadvantages with respect to other low-cost imaging modalities, such as those based, for instance, on ultrasonic echotomography or electrical impedance tomography. Furthermore, microwave are known to provide spatial resolution not as good as X-rays, infrared, etc... However, they are expected to offer high contrast with respect to physical or physiological factors of practical relevance, such as water content, blood flow rate or temperature. Such an advantage could be very significantly increased via the capability of obtaining a time resolution of the order of 10 images per second, compatible with many industrial or physiological dynamic imaging requirements. As a matter of fact, the effective utility of a dynamic imaging system results from a compromise on performances in terms of spatial resolution, time resolution and contrast.

This paper addresses the enhancement, up to 10 images per second, of the time resolution of a planar microwave camera operating at 2.45 GHz [1]. One of the objectives in view is to localize a cooperative target in an unknown medium. Such a problem may be encountered, for instance, during deep protontherapy treatments [2], for which an exact position of the tumor must be known, whatever the exact position of the patient and independently of his respiration activity. The improvement of the time resolution has been addressed at both the data acquisition and processing levels. The acquisition time is directly related to the available signal to noise ratio. Increasing the rate of measurement by a factor 10 requires to increase the incident power of 10 dB, while maintaining acceptable levels (cost, safety, etc...). Practically, the power has been increased up to 10 W which corresponds to a power density equal to 10 mW/cm^2 in the illuminating horn aperture plane and less than 1 mW/cm^2 at a few centimeters. The acquisition time is also related to the operating frequency, but in the case of the existing equipment, the frequency has been fixed at the 2.45 GHz value corresponding to many ISM applications for hyperthermia treatments or material processing. The multiplexer used for addressing the 32 x 32 sensors of the Modulated Scattering Technique retina of the microwave camera has been modified for reaching measurement time of 100 ms per sensor. In addition, the analog low-pass filters of the coherent detectors have also been changed for true integrators. Concerning data processing, a standard linear diffraction tomography algorithm has been used for qualitative reconstructions. With the continuous improvement of the microcomputer performances, processing and monitoring at the rate of 10 images per second is perfectly feasible. While many actual research efforts are devoted to iterative quantitative reconstruction, using diffraction tomography may seem to be quite obsolete. However, refering to so popular ultrasonic imaging equipment, the opinion of the authors is that real time qualitative microwave imaging is worth considering in many, still probably unexpected, applications. Some examples will be shown for illustrating the dynamic imaging performances of the new version of the microwave camera.

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Kalman Filtering in Contacting Microwave Radiometry

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Multifrequency microwave radiometry has been considered for subcutaneous thermal imaging of human body. In many applications of this technique (e.g. temperature monitoring in hyperthermia) time variations of temperature must be monitored. Thermal radiation from a body is received by an antenna which is kept in contact with the body surface. In many systems contacting antennas are waveguide sections filled with high-permittivity low-loss dielectric to ensure broadband matching to tissues. Therefore the antenna itself is a possible source of transient thermal perturbation for the subcutaneous region under measurement.

The feasibility of a transient temperature retrieval from radiometric data has been investigated in the past with reference to the solution of the inverse radiometric problem in a Sobolev space of thermal functions, in order to introduce *a priori* information which is necessary to counteract the ill-posed nature of the problem. More recently the use of a finite state-space model of time-dependent temperature to be retrieved has been considered, in order to deal with the transient behaviour, still incorporating *a priori* information. The model was based on a suitable bio-heat equation together with radiation-type boundary conditions on the skin surface.

In this paper the thermal model is improved by consideration of the interactions between the region under measurement and the contacting radiometric antenna; i.e. *i*) the antenna heat capacity perturbs the evolution of the body temperature; *ii*) the body induces a thermal transient on the antenna, thus changing the (unwanted) antenna contribution to radiometric data. The Kalman filtering is used to account for these interactions as well as unavoidable uncertainties of the thermal model (e.g. blood perfusion rate, sweat rate, treatment-induced heat sources) and noisy radiometric data. In this way antenna contribution to radiometric data is cancelled by the filter. Results for two-dimensional temperature reconstruction will be presented.

Session C08
Friday, July 17, AM 08:40-12:00
Room I
Frequency Domain Methods
Chairs : L. Mendes, T. Itoh

Spatial Domain Evaluation of MoM Matrix Elements

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Integral equation formulations are widely used for the computation of electromagnetic fields in radiating structures. Since no exact solutions are known for the systems of integral equations, the method of moment is applied in order to provide an approximate solution. Using subdomain functions for the equivalent current densities has proven to be of great importance for complex structures like edges or discontinuities of coplanar or microstrip lines. Therefore better subdomain functions, pentahedral functions are presented.

The reaction integrals occuring when applying the method of moments may be represented in the spatial or in the spectral domain. In the spectral domain representation, they have to be evaluated with two-dimensional numerical routines while significant errors can not be avoided. In the spatial domain a fourfold integration has to be performed. For small distances between the expansion functions Green's function in the spatial domain becomes singular, therefore no direct evaluation is possible. In order to handle this problem, the integration of the singular parts is performed analytically. This expression may only be obtained by using a computer algebra program. No fitting procedure is needed for Green's function.

With this new technique, the evaluation of the reaction integrals can be done in the spatial domain only. The accuracy of the results increases and computation time can be reduced by far more than 90%. Some simulations are presented in order to illustrate the advantages of this new method.

RCS Computation Using High Order Derivatives

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The purpose of this paper is to compute the RCS of a composite target by high order derivatives calculation and use Taylor or Pade approximation, according to the frequency parameter.

At each frequency, the direct RCS problem is solved in two steps : first interior problems are solved for several independents functions at the boundary, in order to give a basis of solutions. Secondly the infinite radiation condition is assumed by integral relations, for a given incident field, such as to calculate total field's coefficients in the basis.

In this approach we chose one frequency to compute the fields and theirs derivatives respect to the frequency, until a given order N. We consider extension of the fields for complex "frequency" and let be 'D' a complex domain in which they are holomorphic. Then the Taylor's serie give us a good approximation of the quantity. A problem is to know the 'D' domain, in particular all eigen value, or resonance frequency of discretized problem, and for each kind of boundary condition. We develop a numerical method to find these frequency. An other problem is to give a solution in a bigger domain of 'D', by Pade approximation.

Some numerical results are obtain, concerning 2D case circle and "naca" of about ten wave-length. 3D case should be obtain by the same way. This study will continue by derivate all step of RCS calculation, which in fact is an exterior problem.

Fast Algorithm Applied to BEM to the Analysis of Cutoff Wavenumbers of Ridged Waveguides

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The goal of this paper is to propose a new procedure for solving homogenous problem in ridged waveguides. The method is applied to the integral equation. This procedure is based on the use of a monotonous function instead of the usual determinant to solve eigenvalue problems. The combination of the conventional boundary-integral equation method and a segmentation technique, i.e., boundary element method (BEM) is used. Through discretization, the integral equation with a scalar Green's function is used to determine the mode spectrum in ridged waveguide. Thus, using the Galerkin procedure the eigenvalue equations, whose elements are transcendental functions of the frequency, are reduced to a matrix eigenvalue problem [A][X]=0. Between others techniques, this system can be solved by finding the eigenvalues as zeros (or minimum) of the determinant of [A]. In this paper, we use a systematic procedure, which applied on BEM, leads the small-size matrix eigenvalue problem. The efficiency of this approach consists in vanishing of a function which results from the building of a particular quadratic form of the operator appearing in the formulation of the problem rather than vanishing the determinant itself. This built function has the intrinsic property to be monotonous and to have the same zeros as the determinant. Accordingly, it is possible to save a significant amount of computation time and to avoid that some zeros are missed. The automation of this algorithm is obtained from the examination of the geometry of the structure. Very agreements have been found when the solutions obtained for TM modes are compared with the ones obtained by the classical method.

Improved Spectral Iteration Technique for the Scattering from Metallic Cylinders

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The use of the EFIE static solution, incorporating the correct edge behaviour, as an initial estimate of the current distribution in an iterative scheme, is considered. The procedure for improving the initial form of the current density is developed by manipulating the integral equation in the Fourier transform domain. The idea takes advantage of the fact that the solution of the integral equation for the surface current is not obtained by matrix methods, so we circumvent the problems due to matrix of prohibitively large dimensions. By formulating the problem in the spectral domain, the integral equation becomes an algebraic equation, suitable for easy manipulations on computers.

Imposing the static solution of the current as first step in the iterative solution for the Freedholm integral equation of the first kind means to extract the singular part of the equation and consequently improve the convergence. Diffraction by strips, semi-infinite conducting wedges, equilater triangular and square cylinders are considered as illustrative examples of the method, which is valid in the entire frequency range, including also the resonance region. Here, we present the results obtained for the problem of electromagnetic diffraction of a uniform E-wave by a square cylinder (fig.1).

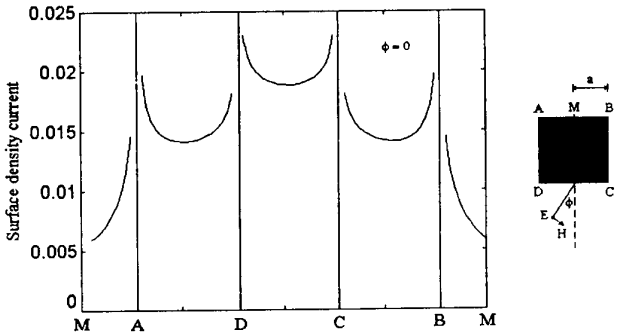

Figure 1 : Magnitude of induced surface current density on a square cylinder with ka=1, f=0°.

The curve depicted in fig.1 show the surface current density on a square cylinder with ka=1, where a is the half of the length of a side; the result , obtained with 10 iterations, is referred to an angle f=0°, which corresponds to an incident wave perpendicular to the side DC .The procedure depicted with semplicity is applicable to more complex structures like printed circuits on stratified dielectric support where the Green's function is known in the spectral domain.

Dyadic Green's Function in Spectral Domain for the Analysis of Multilayer Cylindrical Structures

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Telecommunication in combination with computer controlled systems is becoming more and more important, which can be seen in satellite systems for mobile communications and navigation. In these and many other arrangements it is required that the antenna, the eye of a system, is mounted directly on the surface of a curved body. Therefore, microstrip antennas are well adapted, because of their feasibility to conform to an surface. To analyse and to design a conformal microstrip antenna and a suitable feeding network, especially on cylindrical bodies, several numerical algorithms have been applied.

For a full wave analysis with the integral equation technique, the Green's function must be determined. In this paper the dyadic Green's function is derived for multilayered cylindrical structures with metallizations in arbitrary interfaces. The common approach fullfills the continuity conditions at each interface separately, which becomes complicated if multiple metallizations must be taken into account. The presented Green's function combines all continuity conditions in one matrix equation by means of a network representation and is therefore easy to implement. In short, the following description characterizes the presented Green's function.

The cylindrical structure may be open in radial direction to include radiation effects. Conducting cylinders and metallizations are optional, so that the analysis also includes dielectrical and optical waveguides. Additionally, a complex permittivity can be used for lossy dielectrics or non-ideal metallic cylinders and the structure may be built up out of radially inhomogeneous substrates. Furthermore the radiation for metallizations on cylindrical segments with metallic or magnetic boundary conditions can be determined.

It is shown how to build up the system equation of the whole structure in general, followed by some well know examples as the dielectric rod. Together with numerical results the applicability of the presented dyadic Green's function to some of the described structures is demonstrated. General parameters like the resulting propagation constants are compared with exisitant results in the literature.

Electromagnetic Field Computation in Axisymmetric RF Structures with BEM Applied to Multipacting Analysis

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Electron multipacting [1], [2] is a major problem in rf structures, especially in superconducting cavities. Multipacting occurs when free electrons, accelerated by the rf field, strike the surface of the cavity and release secondary electrons, which repeat the process and, rapidly cause an electron avalanche. This electron discharge absorbs the rf energy and may cause quenching and breakdown of high power rf components like couplers and windows. The phenomenon starts if certain resonant conditions for electron trajectories are fulfilled and if the impacted surface has a secondary electron yield larger than one.

In multipacting the important phenomena related to the electron dynamics take place in the vicinity of the surfaces. Furthermore, since multipacting is sensitive even to small perturbations of the rf field, the field computation near the cavity walls needs special attention. Our purpose is to present an accurate time-harmonic field computation algorithm based on the boundary element method (BEM) [3].
Our algorithm is capable of modelling axisymmetric resonators having both electric and magnetic ends, and of modelling segments of coaxial or circular waveguides having possibly ceramic dielectric windows. In waveguides this leads to modelling the standing waves. For
multipacting we also need to consider traveling and mixed waves, which can be generated by appropriately combining two standing wave solutions. The discussion here is confined to axisymmetric fields.

We use a standard boundary integral equation approach based on the Stratton-Chu formulae with the free-space Green's function. The solution of the integral equations is found by using the Galerkin method with piecewise linear basis functions. This discretization leads to a homogeneous matrix equation, which is solved for a nontrivial solution using the singular value decomposition of a matrix. Furthermore, we have developed accurate integration quadratures and used elliptic integrals to evaluate the singular integral equations numerically.

Due to the field singularities at the junctions of the dielectric and metal surfaces, the BEM turns out to be numerically instable. We can essentially improve the numerical stability by overdetermining the equations on the surfaces of the dielectric window. We illustrate the accuracy of the method in some test cases, where the analytical solutions are available.

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On the Charge-Modeling Capabilities of a Class of Current Basis Functions

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Integral-equation solvers of computational electromagnetics rely on the representation of the unknown function (usually a current distribution) in terms of some known basis functions (BFs). Among various possible choices, piecewise linear functions defined on rectangular subdomains (rooftops or RTs) and triangular subdomains (RWGs) are commonly used in the numerical solution of the surface integral equations.

There are several considerations involved in the choice of the right basis and testing functions. Some of these considerations are reported in the literature. In this talk, we advocate one more constraint: the BFs chosen to model the electric current should also support a consistent and valid charge approximation. This is because the charge distribution is inherently and implicitly approximated by the divergences of the current BFs. We analyze a number of different BFs (including the RT and RWG BFs) with respect to how well they model the charge distribution,
in addition to the current. This analysis is carried out by the help of the topological properties of open and closed surfaces meshed into networks of triangles and quadrangles. The topological information is used to relate the numbers of degrees of freedom (DoFs) supplied by the current approximation and required by the charge approximation.

The need for current basis functions to properly model the charge distribution is demonstrated by several examples. In some of these examples, the basis functions seem to be perfectly legitimate when only the current distribution is considered, but they fail to deliver a correct solution of the electromagnetic problem since they are not capable of properly modeling the charge distribution on some surfaces.

A New Method for Electromagnetic Simulation of UMMIC's

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Uniplanar Monolithic Microwave Circuit(UMMIC) has been developed in resent years. It uses Coplanar Waveguides(CPW) as main transmission line.

The complexities(coupling and distributed effects etc.) of the UMMIC usually lead to big discrepancy between the characteristics of design and product. Besides, it is impossible to adjust the UMMIC after it has been made. Therefor the design of UMMIC should be perfect, and it is necessary to analyze UMMIC according to the field theory approach.

In this paper a new method, Equivalent Fiction-Line Method(EFLM), is proposed for electromagnetic simulation of UMMIC's. The CPW can be approximately seen as an asymmetrical tri-strip-line , which consists of center strip, left and right side-strips. Directly applying the tri-strip-line can also get a good approximation. In analysis of CPW circuits by means of Moment Methods(MM), it should be taken account that a source segment contributes to the field point located at center conductor. In the source segment, the current on left side-strip is same as the one on right side strip. Their amplitude is a half of the current on the center strip. The two side-strip's currents give similar contribution to the field point. Therefore, the effect of the two side-strips can be substituted with an equivalent strip, which is called a fiction-strip. The fiction-strip and the original central strip form an equivalent twin lead transmission line of CPW. The effective distance between the twin line can be determined by comparing the two characteristic impedances that one comes from conformal mapping and another is carried out with MM. The closed form expression of the distance is given in this paper. Besides, it should be pointed out that the method can save much computation time because the segment and analysis of a CPW circuit only face to the central strip in the computation for the effect of the fiction-strip can be accounted to the Green function for central strip.

A C-program is written for EFLM, and a variety of structures (such as a CPW band reject filter, some common CPW discontinuities etc.) have been simulated. The results have good agree with the existing data. It is proved that EFSM is simple and reasonable, and the idea of the method is very helpful to realize a unified simulation method of complex MMIC's with many kinds of transmission lines.

Time and Frequency Features of Resonant Wave Scattering by Waveguide Open Resonators

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Resonant wave scattering phenomena are complicated and depend on large number of parameters. Their reliable qualitative and quantitative analyses with subtle distinction of various effects is impossible without accounting for the dynamic peculiarities of spectrum set elements of corresponding waveguide open resonators; without development versatile robust and efficient algorithm for solving scattering initial boundary value and boundary value problems in time and frequency domains and spectral problems concerning eigen field modes in complex (non physical) domain of frequency parameter. For the rather diverse set of step resonant discontinuities in circular and coaxial waveguides the imperative numerical algorithms and their code implementation have been developed. They are based on the method, fulfilling the idea of analytical regularization of the ill-conditioned matrix equation of the first kind, arising in mode matching technique [1].

The specification and phenomenological analyses of possible eigen quasi stationary field modes and regularities of their occurrence in resonators, described above, have been carried out. The phenomenon of linear "interaction" of eigen modes in waveguide resonators that gives rise to mode coupling and occurrence of hybrid modes have been connected with the fact of closing up of eigen frequencies (eigen values of spectral problem) in complex frequency domain. This phenomenon was analytically described and numerically investigated. The existence of eigen modes with super high Q factor in resonators, loaded in radiation channels* and several others have been found out and studied in details. The predominant influence of spectral characteristics of waveguide discontinuities, treated as waveguide open resonators, on the forming of the resonator's response to stationary and non stationary external excitation have been analytically proved and numerically illustrated.

Individual correspondence and "responsibility" of certain eigen modes of resonator (investigated in spectral problem) and occurrence of the regimes of total transmission or reflection of waveguide waves (in diffraction problem), the regimes of complete wave or wave packets transformation when passing through resonator and several other interesting operating modes of resonator, enabling their application as efficient frequency and waveguide mode filters have been found out (frequency domain).

For the determination and investigation of individual influence of the spectral elements on the formation of the characteristics, describing transient processes in open waveguide resonators, we used the technique of narrow frequency "windowing", applied to amplitude-frequency characteristics of resonator with further transform into time domain. Certain type of waveguids resonant discontinuities electromagnetic portraits gallery have been obtained and described. Relying on this information one can purposfully selects the resonators parameters and type of excitation for design of devices with qualitatively various characteristics.

*In terms of diffraction problem that means that such type of resonances occurs when in waveguides, on which the resonator is loaded, one or more modes can propagate

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Session D08
Friday, July 17, AM 8:40-12:20
Room 120
Computational Electromagnetics in EMC Applications

Organisers : L. Pichon, A. Razek
Chairs : L. Pichon, A. Razek

WIRE LINE MODELLING BY THE FINITE ELEMENT METHOD

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Traditionally, the finite element method (FEM) is considered to be a very powerful technique when the transversal dimension of a transmission line (TL) is large enough to be discretized. On the contrary, when the TL has a small cross section, e.g. a wire line, the conductors cannot be discretized to avoid a large number of finite elements which can make impracticable the numerical field solution. This kind of problems is generally treated by numerical procedures based on integral equations adopting the thin wire approximation [1]. In some applications, when the electro-geometrical configuration is complex, methods based on partial differential equation (PDE) solution are preferred.

In the past two different approaches were proposed using the finite-difference time-domain (FDTD) method, based respectively on the imposition of the field variation of the scattered field as 1/r near the wire surface [2], and on the simultaneous solution of Maxwell's curl equations and telegraphers' equations [3]. A similar approach was also presented using a FEM formulation based on the point-matched finite-element time-domain (FETD) method [4]. In these approaches the EM fields is calculated using a regular grid. To overcome this limitation, a FEM procedure has been recently proposed to analyze two-dimensional configurations [5].

Here, a new finite element formulation is presented to analyze EM fields in complex configurations when there are wire lines embedded in the domain. The field solution is obtained through a finite element procedure based on Whitney elements formulation. The originality of the procedure consists in the modelling of a wire line by the FEM. The wire embedded in the domain is subdivided into a discrete number of wire segments in an opportune way: each wire segment coincides with one edge of the finite element mesh used to discretize the space. To take into account the physical dimensions of the wire, the functional is adequately modified in all finite elements which share a wire edge. Illustrative examples of the proposed procedure will be given.

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Use of Finite Element Method to Optimise the Anechoïzation of a Faraday Box

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Anechoïc chambers are currently used for indoor antenna measurements, electromagnetic interference measurements (EMI) and electromagnetic compatibility measurements [1]. The back reflections due to the walls of the chamber have to be minimised so that the sources radiate like in free space.

In order to cover a large absorption spectrum, two types of absorbing materials are used at the CEGELY: dielectromagnetic multilayer composites operating in the range 200 MHz - 1,5 Ghz and threads consisting of a resistive core and a ferromagnetic jacket for lower frequencies (30 MHz - 200 MHz). Threads are placed in front of the multilayer composites in the 3 directions of the space and connected electrically to the walls. The incident wave induces currents in the loops formed by the threads and the energy is dissipated in the resistive core. This process is economic but the arrangement of the threads have to be optimized: the absorption strongly depends on the distance between the threads, the distance between wall and threads or the number of layers.

The objective of this paper is to show how this optimization has been performed using a 2D Finite Element (FE) package. The developed formulation works in the frequency domain [2]. It handles dielectric, permeable or absorbing materials. Free space radiation is taken into account using either absorbing boundary conditions or boundary integral equation. In the case of the Faraday box, the walls are modelled as perfect electric conductors. The 2D approximation has been validated by comparison between the computed and the measured stationary wave amplitude. It has been done for the range frequency 30 MHz - 200 MHz for a vertically polarised source.

Figures 1, 2 and 3 show the amplitude of the electric field at 200 MHz respectively for a complete reflective box, for one configuration of threads in the same box and in free space. The radiation source is located in the center of the symmetry plane. The introduction of the threads allows to reduce strongly the stationary waves rate. Note that this configuration works fine for low frequencies but is not efficient for higher frequencies (> 200 MHz) because the inter-thread space is then larger that $\lambda/4$.

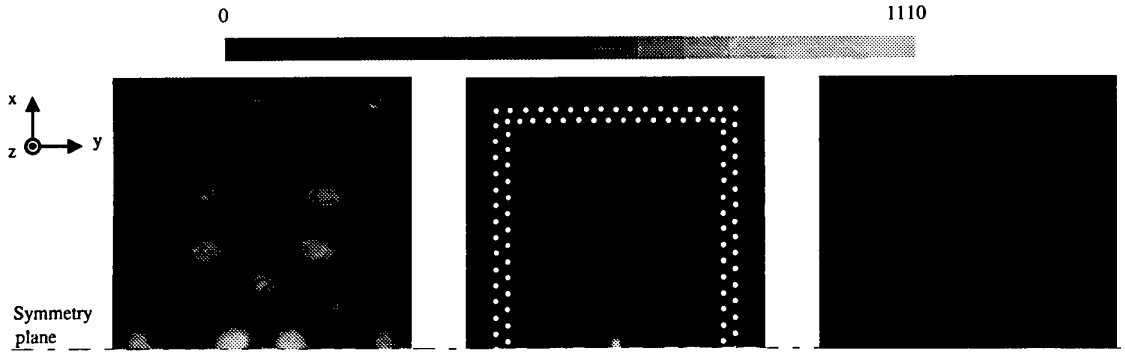

Fig. 1: E_z field in a complete reflective box.

Fig. 3: E_z field in a complete reflective box fitted with absorbing threads.

Fig. 2: E_z field in free space.

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EM Field Numerical Analysis of Nonperfectly Shielded Enclosures in Time Domain

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Prediction of the shielding performances is a very important topic in electromagnetic compatibility in order to prevent disturbances in electrical and electronic apparatus and systems. The main difficulties encountered in the numerical prediction of the shielding practice are due to the complexity of the shielding phenomenon which include both field penetration inside the shield barrier and magnetic flux leakage around edges and apertures.

The modeling of shield barriers using partial differential equations techniques is a well known critical aspect since the numerical prediction of the field inside a conductive region requires a very fine discretization to take into account the field penetration. In fact, in order to achieve a good numerical accuracy, the dimension of the cell grids must be much smaller than the penetration depth. However the fine discretization leads to a heavy memory storage and a considerable CPU time in the field calculations so that in some cases the numerical solution could become impracticable.

Recently, numerical models based on the finite element method have been proposed [2]-[5]. They are suitable to analyze the EM field taking into account both magnetic field penetration and flux leakage.

Here, a time domain application is presented. The shield is eliminated from the computational domain where new boundary surfaces appear. On these new boundaries, boundary conditions of the third kind are applied [5]. The tangential fields on the boundaries are constrained each other by the shielding theory, since the propagation of the tangential fields in the conductive shield barrier is described by the transmission line theory [1]. If the field equations are given in terms of the complex Laplace variable, it is possible to calculate the transient fields via the inverse Laplace transform. Using opportune formulas, the transient field in shielded enclosures can be calculated by convolution integrals which are computed by recursive integration schemes [6].

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Fast Estimation of the Shielding Efficiency of Ferromagnetic Material using an Effective Reluctivity

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The calculation of shielding arrangements with ferromagnetic material and sinusoidal excitation at power frequency is one of the challenging topics in EMC. In recent years problems concerning the shielding of power cables, voltage distribution stations etc. in order to prevent technical devices and human beings from the disturbing influence of electromagnetic fields, rose significantly.

The main aspects of the calculation are the choice of the material model and the numerical method for the thin shielding layer. Besides that the calculation must be efficient concerning the need of computation time and memory and - of course - reliable, which should be checked by comparison with measurements.

Although the magnetic flux density inside the shielding layer normally is far away from sa-turation, which keeps the influence of higher harmonics low, a linear calculation is not possible due to nonlinearity of the characteristics of the ferromagnetic material (e.g. constructional steel). Further on it is recommendable to include the hysteresis effect which may be significant already for low values of the field quantities.

The effective reluctivity method [1,2] which is based on a transformation of the material characteristics and is used by the authors in conjunction with a standard nodal FE method ful-fills the mentioned requirements: it is reliable, fast and efficient. Of course it can be applied only in the case of restricted influence of higher harmonics and the hysteresis effect can be ta-ken into account only in a global manner by considering the losses, thus leading to a complex valued reluctivity [3, 4]. Nevertheless it produces accurate results for the estimation of the ef-ficiency of shielding arrangements.

The advantage of the effective reluctivity method in comparison with transient calculations is the low need of resources and consequently possible combination with optimization procedures.

The full paper will include an outline of the method and the used complex Newton-Raphson method as well as a short review on different possibilities of the determination of the effective reluctivity and a comparison between calculation and measurement results.

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Recent Improvements of the Time Domain Methods Applied to EMC Problems

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The last years, time domain approaches have been extensively used to solve EMC problems even for frequency response determination : the TLM or FDTD methods for volumic objects, the integral equations for wire structures.

However some EMC problems require more improved approaches :

- The frequency bandwidth of the EM perturbation illuminating big sized structures is increasing. A topological approach is necessary to avoid prohibitive run time and memory space. In fact hybrid methods are applied. Three examples will be described :

  - FDTD-UTD to study the radiation of an antenna located on a big structure.
  - FDTD-EFIE for studying, wires or ribbons of printed circuits in a box or to modelise objects illuminated by wire simulators.
  - FDTD-FDTD, a zoom technique is used to descretize accurately the head of a missile, using not so small cells for the descretisation of the other parts of this missile.

- The study of inhomogeneous and dispersive media is an up to date problem considering the interaction between the mobile phone and head.
Dispersive dielectric characteristics are already introduced in the FDTD scheme, using Debye or Lorentz models ; recently a more realistic Cole-Cole dispersive medium has been studied : its characteristics are deduced from a differential equation using fractional derivatives. This equation is associated to the Maxwell equations to be solved by the FDTD Method.

- A more efficient approach is now necessary to analyze circuits taking into account electromagnetic behavior : the approach used associates the FDTD method to the classical time domain CAO codes to analyze circuits with linear, non linear or active elements at high frequencies.
All these approaches will be presented in details.

3d Electromagnetics with MoM on PC's

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1 - INTRODUCTION

During the last decade, Unix machines controlled the scientific applications.
PC with 333 MHz Pentium equiped with multiprocessors and able to access more than 512 Mbyte RAM memory are on the market. The cost of the PC computer as well as the available interface tools and their ability to be easily installed in the testing room make today the PC a real competitor with respect to UNIX work-stations. We present a new tool named EMC^{2000} with superior capacities with respect to old developments on Unix work-stations.

2 - EMC^{2000} PRESENTATION

The software will be shown on action during the presentation. It use arbitrary objects, together with a MoM method & the equivalence principle merged with electromagnetic topology aspects. The theoritical details have been described in published papers (See references).

3 - ACTUAL & FUTURE TRENDS FOR EMC^{2000}

During the presentation, the following aspects will be discussed :

- Out-of-core solver : method and consequences on the software architecture
- Aperture treatment : used method
- Cavity treatment : recent progress in Floquet's series calculation
- equivalence principle mixed with topologic aspects and Green's dyadics

An on line demonstration of the PC cabilities will be given on a screen during the presentation by means of a portable PC.

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[12] J. P. ESTIENNE Atelier de travail CNES Oct 96 'Methode des moments pour des objets de grande taille'
[13] J. P. ESTIENNE, J.G. FERRANTE Mars 98 Journées d'études SUP'ELEC 'Méthodes de calcul numérique pour la modélisation et la conception d'antennes : Optimization of antenna calculation on PC platforms using MoM'

Simulation of Complex Systems in EMC

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The study of problems of interest in electromagnetic compatibility falls into two categories, namely, isolated components and integrated systems. In the first category the objective is to characterize simple interactions such as penetration through a slot or estimation of current flows on a simple object. In the second category a multitude of interactions is studied in a complex system such as an equipment cabinet subject to incident radiation from an antenna placed in a particular environment eg screened room or open area test site. The focus of the current paper is on whole system modelling and the problem associated with it. The examples which will be shown are obtained using the TLM method [1].

In whole system modelling a number of simplifications have to be made to permit efficient numerical models which can be implemented on a workstation. The individual interactions which the model must encompass are, penetration through electrically small and large apertures, coupling and propagation in thin multiwire cables, description of absorbing and lossy materials, penetration by diffusion through thin imperfectly conducting walls, antenna modelling in transmitter and receiver modes etc [2]. All these modelling aspects will be surveyed and the overall modelling philosophy will be explained with reference to techniques developed for the TLM method. A general simulation example will be presented showing an equipment cabinet with an aperture placed inside a partially damped screened room (using carbon loaded foam and ferrite tiles) and subject to radiation from a dipole antenna. Several aspects of the simulation of this typical EMC test problem will be presented namely the effectiveness of the screened room damping, the screening effectiveness of the equipment cabinet, emission from the cabinet and methods for reducing it. The ability of field codes to assist EMC designers and the limitations of these codes will be discussed.

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Analysis of the Computational Efficiency of Domain Decomposition Using Admittance Matrix Networks

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The analysis of numerous complex electromagnetic interaction problems, as they appear in the design of aircrafts for example, can be reduced to the computation of currents in electronic components induced by electromagnetic waves propagating through a system of cavity-like compartments which interact by means of a number of apertures.

An interesting idea, for the resolution of this kind of problems, is to use the decomposition of the interaction configuration into subvolumes and to describe them by admittance parameters on their boundaries, which can be computed in a completely independent way. In order to obtain the quantities of interest in the complete interaction problem, a network equation can then be constructed, which accounts for the continuity conditions to be imposed on the tangential fields on the apertures between subvolumes.

The domain decomposition can be represented by a graph. In this "Interaction graph", nodes represent subvolumes and branches represent apertures between subvolumes. The matrix description of the topological structure of this interaction graph can be utilised to construct the network equation directly from the admittance matrices of the subvolumes.

The network equations obtained in this way have a block structure which is very sparse in general. The size of the blocs is determined by the number of unknows on the interfaces between the subvolumes and the sparsity depends on the topology of the interaction graph.

In this paper, we first explain the relation between the block structure of the equation and the interaction graph topology and then we discuss several techniques to solve the linear systems, which we compare as to their efficiency (computation speed and memory requirement) by testing some representative special cases.

The techniques we investigate are :

- Iterative techniques of the conjugate gradient type (e.g. BiCGstab) and of stationary type, in which the sparseness of the system can be exploited to reduce memory usage in a straightforward way,
- Factorisation type techniques (e.g. LU), where the exploitation of the sparseness of the systems depends on the order of the operations.

In the second type of resolution methods we test two schemes for numbering the unknowns

- Local optimisation schemes, like minimum degree algorithms,
- Algorithms which transform the complete system matrix into one with a structure which minimizes "fill-in" and maximizes parallelisability.

We present test results for networks, consisting of generic elementary volumes with one, two or three apertures which can be grouped together into interaction configurations with topologies of varying complexity. The topology of the network is varied in order to show the effects on the sparseness of the equation and to test our numbering schemes. The number of unknowns on the interfaces is varied in order to show the efficiency of the various solution techniques.

A Numerical Approach of the Behavior of a FACT Component and his Package submitted to an ElectroMagnetic Aggression

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This paper deals with approaches made by numerical simulation with codes DESSIS-ISE, SPICE, ELF3D and ELFI3S permitting to study the behavior of electronic components and their immediate environment, i.e. their packages, when submitted to an ElectroMagnetic (EM) aggression. We investigate on the EM susceptibility of an input buffer (FACT).

The increasingly compacted assembly of electronic components onto printed circuit boards (PCBs) and the increased integration of integrated circuits (IC) themselves involve ever more reduced noise margins and a growing system sensitivity to ElectroMagnetic (EM) aggressions. EM disturbances may differ in their origins. Within the investigated frequency range (from 100 MHz to 20 GHz), the EM disturbance is considered to interact with the system and reach up to the component through the filar links, the printed circuit board (PCB) and finally the component packaging rather than directly interact with the silicon chip of the component.

We first present code DESSIS-ISE [1] dedicated to the numerical resolution of semiconductor physical equations for the silicon part of the component. We then demonstrate how we associate these equations with those of electric circuits allowing for the integration of the immediate environment effect of the component which is constituted by the packaging. When studying the EM aggression or even the nominal operation of the component, we model the packaging in the form of an equivalent electrical diagram based on self-mutual matrix [L] , resistor matrix [R] and capacity matrix [C]. The difficulty is to describe this electric diagram and estimate the value of the different passive components that constitute this electric diagram.

In second to determine the three matrices [R] , [L] and [C], two codes are used :
- code ELFI3S [2], a 3D frequency electromagnetic code, based on the boundary finite element method (unit surface area) which, when used with HENRY3D parameter extraction post-processor permits to determine [R] and [L],
- code ELF3D [3], a 3D electrostatic code based on the collocation method to boundary finite elements (unit surface area) to determine the surface charges for given potentials and then permits to determine [C].

We finally present results yielded for an EM aggression of CW (Continuous Wave) type on a FACT (Fairchild Advanced CMOS Technology)-family buffer with a comparison between the two codes DESSIS-ISE and SPICE [4].

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Thin Wall Shielding : A Comparison of Approximate and Exact Solutions

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If thin walls have to be discretized in the numerical treatment of shielding problems the computation tends to be become combersome since the fine discretization needed in the thin shielding walls will enforce an over all mesh with a great number of nodes.

To overcome this diffculty the following approximations can be used.

The field distribution inside the shielding wall is locally replaced by the field distribution in an wall stretching out to infinity in two directions.

The electric and the magnetic field strengths along a coordinate directed normal to the (inner or outer) surface of the shield are approximated by a step function (for the thin shield).

Thus the shield is replaced by electric and magnetic current sheets flowing on an surface positioned between the inner and outer surfaces of the shield. The intensity of the electric and magnetic current sheets depends on the material parameters of the shield, on the local wall thickness and on the operating frequency.

As an example the shielding efficiency of a magnetic dipole with arbitrary position and orientation inside or outside a permeable and conducting hollow sphere is considered.

To check the validity of the calculations the results are compared with the analytical solutions which have also been computed for arbitrary dipole positions and orientations.

The results obtained can serve as a basis for the computation of the field excited by current flowing in a loop of arbitrary shape. In this case the elementary contributions of dipoles in a surface bounded by the contour of the current loop must be integrated.

Session E11
Friday, July 17, AM 08:40-09:40
Room K
Transmissions Lines
Chair : G. Alquié

Analysis of Planar Transmission Lines with Floating Strips

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Quasi-static analysis of various printed circuit transmission lines is widely used in the literature to model their lectromagnetic behaviors at low frequency. To achieve this goal, a potential-charge density (PC) integral equation is usually derived considering free charges on metals as unknowns. Alternatively, for slot-dominated structure , it can also be characterized in terms of aperture electric fields and solved through a charge-field (QE) integral equation [1]. In [1], all metal strips were considered on the same plane and no floating strips were considered. Floating strips may be used in the design of a tightly coupled microstrip coupler [2]. In this summary, we find that floating strips can automatically be taken into account in the solution process. A main step in [1] is to assign accumulation charges along each slot. Initially, the total charge on the outside ground plane is assumed zero. Therefore, the accumulation charge on the leftest slot is zero. The amount of charge increased while moving to the next slot is equal to total charges on the strip between two considered slots. For a floating strip, the total charge is zero. Therefore, it can be incorporated in the solution process. We study even and odd mode characteristic impedances of two strips each with equal width. Another floating strip is placed between them. It is shown that the even-mode impedance is not much influenced by adding the floating strip, while the odd-mode impedance is decreased with a wider floating strip. The coupling is expected to increase.

Derivation of charge field integral equation for planar transmission line with strips situlated on at least two reference planes may be referred to a parameter-extraction-like approach [3]. For quasi-static analysis by PC method, we put a magnetic wall at a suitable reference plane. On the contrary, an electric wall is needed in QE formulation.

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The Problems of Syntheses and Diagnostics Dielectric Layer and Effect of Intertype Coupling of Own Electromagnetic Fielfs

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The spectral problem of a flat dielectric layer with ever varying permittivity is solved. The initial problem is equivalently reduced to the second-kind integral equation in the sought function. By applying quadrature method, we arrive at the homogeneous system of the second-kind linear algebraic equations with the nonlinear entrance of spectral parameters. The resulting dispersion equations yield not only the regular spectrum points but the Morse critical points (MCP) as well, here dispersion curves can be constructed providing effective algorithms of analysis and synthesis of the dielectric layer properties.

The resulting dispersion equation permits the approximation of the initial spectral problem to the sequence of characteristic numbers being the solutions of the corresponding transcendental equation. Contrary to the known approaches, the eigenfrequencies and propagation eigenconstants are analyzed to be on the Riemannian surfaces. For the generalized wave-oscillation spectral parameter, the analysis is made on the complex Riemannian manifold that is a topological product of the Riemannian frequency and wave surfaces. With theory of smooth-mapping singularities, dispersion characteristics of the considered structure can be analytically derived near the isolated nondegenerate critical point that is the MCP of the complex hypersurface. This furnishes a new analysis technique with consequent effective algorithms of synthesis of dielectric media whose eigenfields obey the anomalous dispersion low near the discovered MCP where, in particular, will be realize effect of intertype coupling of own electromagnetic fielfs of the dielectric layer.

The obtained results can be useful in diagnosis problems, wave propagation problems for layered dielectric waveguides within the Kerr approximation, nonlinear dielectric, semiconductor superlattices.

Propagation Characteristics of Dielectric Waveguides by Multilayer Gratings with Periodic Surface Relief

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Dielectric gratings are now widely used in integrated optics and acousto-optics, such as optical gratings, optical couplers, optical waveguide filters, and holography. In the optical couplers, it is important to get blazing effects, because such dielectric grating can radiate the incident energy into the regions above or below the grating. For the case of surface relief type with homogeneous media, the analytical methods and numerical methods for guiding problems have been proposed. However, for the case of surface relief type with an inhomogeneous media , detailed numerical results are not reported because the conventional methods are difficult to analyze this structures.

In this paper, the guiding problems by multilayer gratings with periodic surface relief are analyzed using the combination of improved Fourier series expansion method and multilayer method[1]. In the analysis, the multilayer region is divided into the assembly of stratified thin layers in which the dielectric distribution are expanded in Fourier series. Our approach for the multilayer method differs from that of other method, so that the order of characteristic matrix equation depends on the modal truncation number, but does not depend on the number of layers. Therefore the range of applicability to periodic structures is much wider than that of other method. We analyzed the propagation characteristics for the following profile of grating :

(A) the surface profile $h(z)$ of relief :

$$h(z)=\begin{cases} -z/w & ;0\le x<w \\ -(p-z)/(p-w) & ;w\le x<p,\ p:\text{period of grating} \end{cases}$$

(B) the distribution of permittivity $\varepsilon_2(x,z)$ in the $-d<x\le h(z)$:

$$\varepsilon_2(x,z)=\varepsilon_A\left[1-\delta\cos(\pi x/d)\right]$$

In the paper, we investigate the propagation characteristics and the blazing effects for the dielectric waveguides by multilayer echelette gratings with periodic surface relief for TE_0 mode. In the numerical results, we have found as follows :

1) For the normalized attenuation constants at Bragg region versus p/λ (λ:incident wavelength) as a function of w, there are remarkable differences between homogeneous medium and inhomogeneous medium.
2) For the blazing effects versus d (d : grating depth), it depends on the profile of grating with inhomogeneous medium.

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Session F06
Friday, July 17, AM 8:40-11:20
Room B/C
Conformal Antennas and Arrays
Chairs : D. A. Wingert, A. Papiernik

Conformal Array Antenna for LEO Observation Platforms

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Current X-Band links from LEO Satellites to ground stations are limited in data rates because of their low gain, due to the global coverage by a single beam. For increasing data rate while keeping low DC consumption and for allowing simultaneous links with several ground stations, a multibeam scanning antenna was designed and a demonstrator (up to three beams in three adjacent sub-bands) manufactured for an observation mission at an altitude around 800 km. A « semi-active » Conformal Array was selected (see figure 1) as the best option for such a mission, because of its higher gain compared to a passive fixed beam and its capability of electronic scanning with low amplitude and phase jumps.

For performance demonstration, manufacturing of nominal equipment was limited to that required for one-beam: 1:24 divider, a complete set of eight 3x3 Butler matrices and 24 subarrays (each including 6 patches), assembled on a representative truncated conical structure. No amplifiers were included, and phase control was performed by means of vector modulators test set-up.

Complete tests (radiated patterns, track of ground station) have been performed on the whole antenna and a good accuracy has been obtained by comparing simulations to measurements. The main results can be summarized as follows :

- Optimisation of amplifiers efficiency, all delivering constant and uniform power.
- Very low amplitude and phase jumps when scanning (respectively lower than 0.3 dB and 3° measured on typical trajectories)
- Control unit optimised to Dt=100 ms between commutations and 5 bits phase-shifters
- High gain (20 dBi towards Horizon, compensating range attenuation elsewhere)
- Low mass (less than 8 kg for Flight Model antenna)

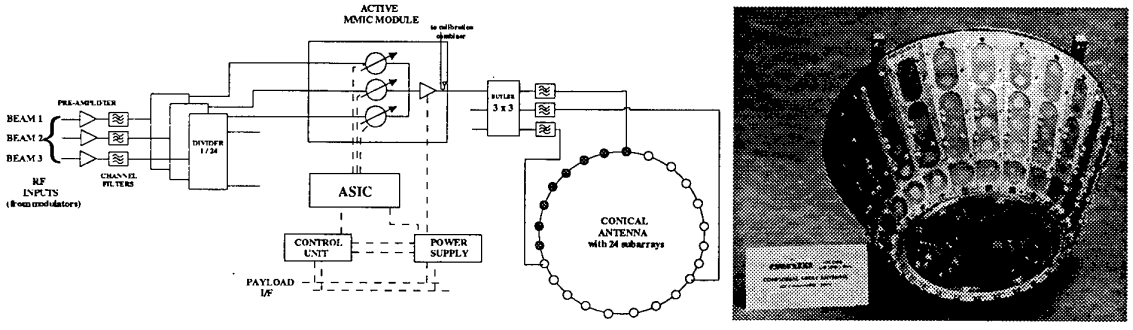

Figure 1 : « Semi-active » Conformal Array

Half and Quarter Wavelength Printed Antennas on a Conical Surface

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This paper presents a theoritical model in order to analyze the performance of microstrip antennas printed on a conical surface. Figure 1 shows the basic geometry of the microstrip antenna on a conical surface.

The cavity model with magnetic or electric side walls is used to calculate the resonant frequency and the input impedance. In this analysis, we assume that the substrat thickness is very small and that the curvature radius of the conical surface is large compared to the operating wavelength. In this case, the losses due to the excitation of surface waves may be neglected [1].

The dominant mode excited determines the field distribution at the patches edges. So the far field radiation pattern are obtained by superimposing the radiation from axial and circumferential equivalent magnetics currents along the patches edges and by using the dyadic Green's function [2].

We experimented two microstrip antennas printed on a 20 open-angle conical surface. We propose the study of half and quarter wavelength printed antennas.

The half wavelength antenna is printed on a substrate with $e_r = 1$, Dq = 0.69°. The dimensions r_a = 18.2 cm, r_b = 21.08 cm, and f_0 = 13°. It is fed by a coaxial line through the ground of the conical surface located at r_1 = 19.9 cm. Due to pratical limitations the patch is assembled on a truncated copper conical surface of length 35 cm. The theoretical and experimental bandwidth are respectively 3% and 3.95%. Moreover, the effects of the practical parameters on the antenna performances are investigated.

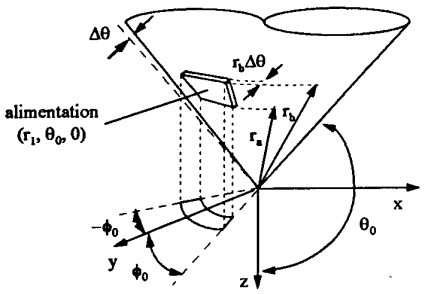

Figure 1 **:**
Basic geometry of a patch antenna on a conical surface

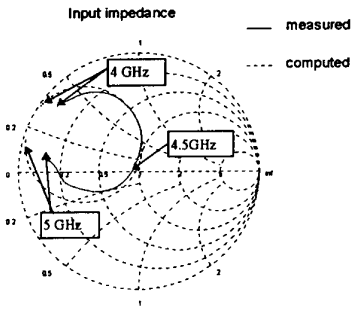

Figure 2 **:**
Input impedance

References

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Analysis of the Rectangular Microstrip Patch Antenna on Elliptic-Cylindrical Substrate

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One of the most appealing property of the microstrip technology is the possibility to realize antennas printed on curved sunbstrates.In the last years several papers have been published on the analysis of antennas conformal to cylindrical, conical and spherical surfaces.

In this work we will present the characteristics of the rectangular microstrip patch antenna printed on an elliptic cylindrical substrate. Elliptic cylinder geometry seems particularly useful when modeling surfaces of the body of aircrafts. The analysis has been carried out by modeling the patch as a cavity with magnetic wall. The field under the patch is expanded in series of eigenfunctions which involve angular Mathieu functions of fractional order. The radiation effects are taken into account by considering an equivalent field distribution on the surface of the elliptic cylinder. The radiated field is expressed as a sum of elliptic harmonics in the spectral domain. A closed form expression of the far field is derived by computing the inverse transform with the method of the steepest descent . The radiated power is calculated and included into the effective propagation constant and the input impedance is then computed. Radiation patterns and input impedance of several configurations will be presented.

Curvature Effects on Radiating Characteristics of a Conformal Antenna of Arbitrary Shape

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In recent years there has been significant interest in conformal antennas and arrays, especially on cylindrical bodies. In this work, the curvature effects of an antenna conformed on a sphere portion are presented. The radiating elements are modelised by finite element. This modelisation allows the resolution of EFIE integral equation by the method of moments.

We will be interested particularly in an broadband dual cross polarised antenna called « star antenna ». This flat antenna, patented in Europe and in the USA [1], is printed on a dielectric substrate (glass-teflon) of very low thickness and arranged parallel to a reflector plane at height H=7mm. Then, in the analysis the antenna will be considered in air medium.

Performances of this radiating plane element for an external diameter equal to 18 mm, are as follows [2] :

- Frequency bandwidth between 6 and 10 GHz.
- V.S.W.R. related to 50 ohms remains less than 2.
- Decoupling between the two inputs is less than -20 dB.
- The cross-polarization level remains at -20 dB below the co-polarization.

The meshing of the conformal antenna is a projection on a sphere portion of this initial flat structure for the analysis (fig. 1).

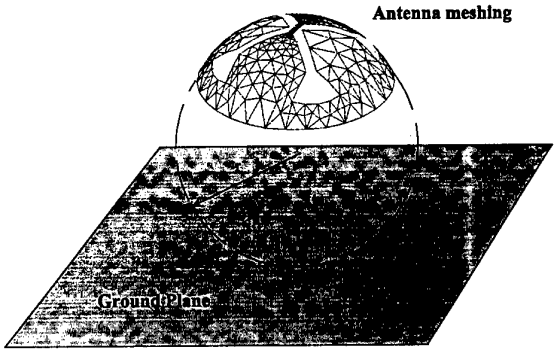

***Figure 1** : Broadband dual cross polarised antenna conformed on a sphere portion.*

We will show the curvature effect of the antenna on the input impedance in all the frequency band. We will show finally that the choice of the curvature allows in certain case to obtain radiation patterns with equal half-beam power in E and H planes (fig. 2).

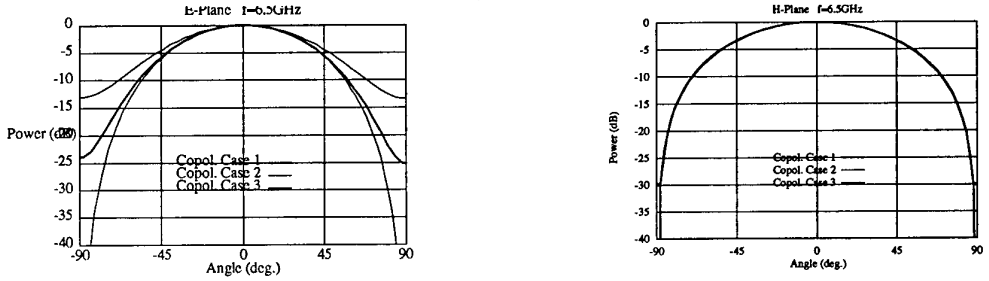

***Figure2** : Radiation patterns for three cases : r=20mm (Case 1), r=10mm (Case 2), r= ∞ (Case 3)*

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Development of a Conformal, Smart Skin Antenna Utilizing Waves in Composite Media

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This paper will review the design and performance data of a conformal 'window' that can be utilized as an antenna. Historically the number of antennae being used on advanced aircraft continues to increase. Additionally, the aperture and the antenna system are required by the user community to employ more features than in the past. This paper will describe one way in which these shortcomings may be overcome. Specifically we will review the development of a conformal, smart skin antenna (or antenna array) that utilizes waves in composite media for its feed network. The antenna elements may then be inserted or removed from the aperture in a simple manner. Alternately, the aperture in which the antenna is embedded may become a microwave transparent, absorptive, or reflective structure on command, thereby encapsulating one feature of the 'smart-skin' concept. This enables a wide variety of antenna utilization's in a small space, therefore reducing the number of antennas, apertures, and RF windows. The device will be modular in that the entire device will be multiple sets of basic, identical, subcomponents. This development then may lead to a dramatic decrease in the number of antennae and apertures on the aircraft, and at the same time be an integral part of the aircraft's structure.

Integration of Conformal, Smart Skin Antenna Assemblies Into Aircraft Surfaces

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Smart skin antenna assemblies typically involve application of unique material systems and complex laminate assemblies. These complex apertures must be integrated into aircraft structures to enable load transfer for structural robustness, compatibility with vehicle operational environments, and durability over long service life. Additionally, the mechanisms for achieving adaptability, (mechanical, electrical, or hybridized) must be accommodated. This paper will review the various means for design and integration of realistic conformal antenna systems. Discussed will be the selection and implementation of material systems meeting electrical, structural, and environmental requirements. Suitability of these materials for the aircraft operational environment will be examined. Items such as: effects of rain erosion, maintenance handling and thermal cycling will be included. Methods for mechanical attachment of apertures will be reviewed along with design for installation/removal and connection to the host aircraft systems. Means for integration of adaptive mechanisms into structurally suitable aperture panels will be reviewed. Comparisons of mechanical properties will be made with conventional aircraft structures that incorporate various apertures. Finally, trades between location of apertures driven by the use of integrated conformal assemblies will be shown. The summary will identify favorable concepts for realistic implementation of conformal, adaptive apertures that can survive the operational environment for a vehicle's service life.

An Overview of Smart Skin Antennas

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Future requirements for multifunction and wideband phased array systems have highlighted the concept of an electromagnetic smart skin. Various antenna structures can be explored for different applications: low frequency band antennas for CNI functions and high frequency band antennas mainly for radar and electronic warfare (EW).

In the case of current aircraft nose radars, where the performances are limited due to their antenna protected by a nose radome, the multifunction and wideband conformal active antennas (smart skin) offers very promising performances as well as potentially extended functional capacities.

Dassault Electronique has carried out conceptual studies, electromagnetic design and simulations, and technological developments on an innovative microwave conformal antenna architecture (electromagnetic smart skin). Moreover, along with its involvement in the commercial telecom market, Dassault Electronique has emphasized the contributions of optoelectronics to the service of conformal antennas. Hence a potential approach based on a microwave/optoelectronic smart skin will be layed out.

In the long term forecast the front antenna of current airborne radar would be favorably replaced by several smart skin parts distributed over the aircraft structure and shared between radar, electronic warfare and communication.

Session G13
Friday, July 17, AM 08:40-11:00
Room M
Microwave Components III
Chairs : B. S. Rawat, O. Picon

Whisperinghispering Gallery Mode Converters

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The whispering gallery mode of cylindrical waveguides is used intensively in gyrotrons. Therefore mode converters are needed to investigate the operation of these devices. In this paper the principle of mode conversion will be presented along with some developed converter structures for the 15 and 38 GHz frequency bands.

In the first approach the mode conversion is carried out between the coaxial TEM mode and the $TE_{16,2}$ mode of a cylindrical waveguide. For that purpose a star type microstrip distribution network is applied which has gaps radiating into the cylindrical waveguide. By a proper arrangement of the radiating elements the $TE_{16,2}$ mode is generated. The layout of that mode launcher is shown in **Fig. 1**. The generated modes are presented by the dotted lines in **Fig. 2**. As seen beside the $TE_{16,2}$ mode a few other modes are also excited at a lower level.

To improve the mode purity spatial mode filters are inserted. These are metallic plates with appropriately designed holes. They transmit the $TE_{16,2}$ mode and reflect the spurious modes. Using the mode filter the mode purity is significantly improved. the result is shown by the transmission response with dark area in **Fig. 2.**

Our other approach applies a conical corrugated transition from the fundamental mode to a higher order mode of a cylindrical waveguide. This structure was investigated by computer simulation using the HFFS (high frequency field simulator) software of HP.

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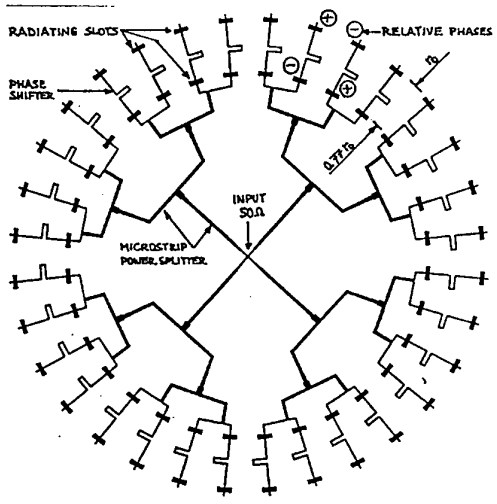

Fig. 1 Layout of the distribution network

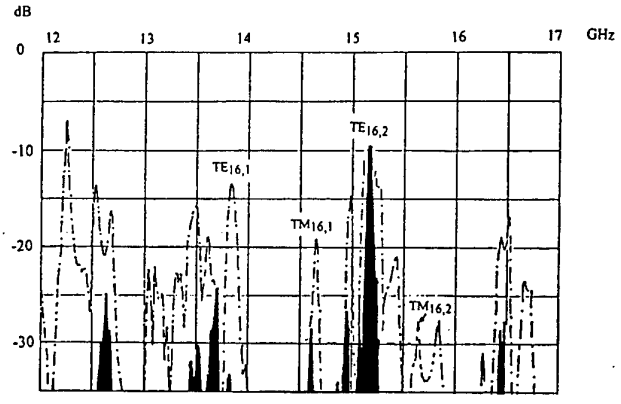

Fig. 2 Transmission response without and with mode filters

The Performance Characterisation Transferred in to the Load Plane for a Microwave Transistor

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After having developed theory of the noisy fourpoles by H.Rothe and W. Dahlke [1] ,graphical representations for the gain and noise figure were first given by H.Fukui [2] and utilized in a lot of works aiming at the design method for the small-signal microwave amplifier.In the last decade , these graphical representations have been focused rigorously on the characterisation of a microwave transistor as a linear two-port, particularly in the utilization of the MMIC design. In [3], a single geometrically derived parameter μ in the load plane has been used as a new criteria for the stability. However this work does not give a complete description for the transistor stability state , because it does not inform about the conditional stability configurations in the load plane. In [4] and [5] , a transistor performance characterisation is made in the input plane using the geometrical analysis based on the graphical representations of the performance measure functions the noise figure F , Input VSWR V_i , and the transducer gain G_T with respectively, the open circuit **Z** and the scattering **S** parameters. These works resulted in a conditional formulation of the constrained maximum stable gain G_{tmax} considering both F and V_i as the degrees of freedom.Incompleteness of these works come from that one cannot observe effects of any external parasitic or the feedback element on the device performance characteristics.

In this work firstly all the possible stability configurations are analysed with their associated unconditionally working areas (USWA) in the load plane so that their necessary and sufficient conditions can be derived. Secondly the performance characterisation using the Günes method is made so that the design configuration is resulted in the load plane, which consists of the USWA , the constrained gain circle famly and the T_1 and T_2 circles combining the required F and V_i . Finally the triplets with G_{tmax} among the infinite number of possible (F,V_i,G_T) triplets are chosen by the similiar processes to those in [4] and [5].

This work will facilitate to see directly effects of any external parasitic or the feedback element on the performance characteristics of the transistor on the load plane and make trade- off among them.

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A Neural Network Approach for the Performance Data Sheets of a Microwave Transistor

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In this work , the performance characteristics are aimed at obtaining in an accurate manner for a microwave transistor using a neural approach. These performance characteristics includes not only the performance parameter characteristics supplied by the manufacterers such as the variations of the scattering [S] and the noise [N] parameters with either frequency (f) or the bias condition (V_{CE} , I_{CE}) at various types of configuration (CT) , at the same time the performance measure parameters noise F, input VSWR V_i , the maximum stable gain G_{tmax} characteristics such as the maximum gain against input VSWR for the fixed noise figures at given bias condition and frequency. In fact , the performance measure characteristics supplied by the manufacturers are very limited amount such as the maximum gain G_{MAX} in the minimum noise figure condition.Neverthless , in this work all the performance curves of a microwave transistor can be obtained using the performance triplet (F, V_i , G_{tmax}) theory [1], which interrelates the performance measure parameters the noise F, Input VSWR V_i , The maximum stable gain G_{tmax} at the fixed operating conditions V_{CE} , I_{CE} , f, CT . Among this type of curves , one can consider the maximum stable gain G_{tmax} against the input VSWR , or the noise figure F , or the bias current I_E , or the operating frequency f while the rest of the parameters are fixed. Furthermore the source Γ_S and the load Γ_L terminations are also provided.

In this work , the microwave transistor is modelled by a neural network which evaluates the scattering [S] and the noise [N] parameter vectors , based upon the fitting both of these parameters for multiple bias and configurations with the target values [2]. So this multidimensional neural network model can predict the [S] and [N] parameter vectors in an accurate manner not only at a single operating frequency around the trained bias condition, which may be named as the single frequency generalization (SFG) , at the same time for the whole operating frequency band for a bias condition not included in the target space , which may be called as the whole frequency band generalization (WFBG).

In the second part of the work, the predicted the [S] and [N] parameter vectors at the fixed operating condition set (V_{CE} , I_{CE} , f , CT) are inputted to the computer programme of the performance triplets [1] and all the possible (F, V_i , G_{tmax}) triplets and their termination couple (Γ_S , Γ_L)s are obtained from the output. The final part of the work is to obtain the performance parameter and measure curves of the transistor.

These types of data sheet are expected to be supplied by the transistor manufacturers in the near future , because it will provide a high level tool of characterising the transistor in the design of microwave circuits , particularly in MMICs.

References

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On the Design of Mach-Zehnder Silicon Waveguides for Sensor Applications

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Silicon optoelectronics have attracted a great deal of interest in recent years [1]. The motivation for building optical devices on silicon substrate is mainly due to its mature processing technology, yielding the availability of low-cost, high-purity wafers and the possibility of integrating these optical devices with microelectronic and/or micromechanical elements. Generally, the main application envisioned for silicon optoelectronics technology resides on the field of optical sensors, which offers several advantages over conventional ones, such as, robustness to hazardous environments, immunity to EMI interference, compactness, and light weight.

Several sensor structures employ an integrated Mach-Zehnder configuration on a rib structure [2]-[4]. A silicon dioxide buffer layer acts as the lower cladding. Since the refractive index of the substrate is larger than the refractive index of the guiding layer, the SiO_2 buffer clad must be made thick enough so that power leakage towards the substrate is reduced. This thickness requirement presents a considerable technological challenge, since deposition of thick high-quality LPCVD silicon dioxide layers is not a trivial process. Thus, it becomes important to find out the minimum SiO_2 buffer thickness which yields a given tolerable power leakage loss. Unfortunately, the technical literature lacks a comprehensive and systematic study on the design of such waveguiding structures.

Here, we focus on the the leakage of power caused by the finite thickness of the lower cladding layer. In order to answer this question a simple analytical formulation based on the well known effective index method (EIM). Our particular EIM implementation additionally includes a transfer matrix formalism for the analysis of leaky waveguides. Also, we analyzed the radiation loss induced by the Y-junction of the Mach-Zehnder as a function of the angle between the two arms of the interferometer. The analysis was carried out by implementing a finite difference based BPM (Beam Propagation Method) algorithm, a method specially convenient for analyzing these structures, solving numerically the Helmholtz equation under paraxial approximation. Our study indicates that the angle should be no larger than 0.02 radians, in order to keep the losses below 0.1dB/junction. Such losses can reach 3dB as the junction angle approaches 0.1 radian. Regarding the power leakage better results are obtained for Ohkawa's structure [2], which shows a power leakage loss lower than 0.01 dB/cm for a SiO_2 buffer thickness of 1.5 microns. In all three mentioned structures [2]-[4], the loss is smaller than 1 dB/cm for a minimum thickness of 2 microns.

Acknowledgment

This work was partially supported by the Brazilian agencies CNPq, CAPES, and FAPESP, as well as by the programs RECOPE, PRONEX, and RHAE.

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Analysis of Coupled Ferrite Nonradiative Dielectric Waveguides

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The nonradiative dielectric waveguide (NRD) [1] is a well-known technology for millimeter-wave applications. Simplicity and low-loss nature are attractive properties of the NRD technology. Several NRD devices, such as filters and directional couplers, have been proposed in recent years, most of them using isotropic materials [1]. Since useful devices in microwave and millimeter-waves, including circulators, isolators and phase-shifters, are all made using ferrites, characteristics of electromagnetic wave propagating in ferrite NRD guides have also been analysed [2]-[4]. However, the use of ferrite to control the wave propagation characteristics of coupled NRD waveguiding structures has not yet been investigated.

In this paper, the performance of coupled ferrite NRD guides is analysed. The two conventional isotropic slabs of a NRD directional coupler are replaced by ferrite slabs. The gap between the two identical slabs is made by an isotropic dielectric and the external biasing magnetic field is applied normally to the metal planes. Since the waveguiding structure is symmetric, the analysis can be carried out by even and odd modes. The electromagnetic fields components in all regions are written in terms of the electric and magnetic components in the same direction of the external biasing magnetic field [4]. The boundary conditions applied to the dielectric interfaces lead to the characteristic equation for the propagating modes. These modes have all six components. Only modes corresponding to the LSM modes in the isotropic limit case were considered. Numerical results for propagation constant of the even and odd modes as a function of coupling spacing were obtained for commercially available ferrites for millimeter-wave applications. Ferrite parameters were calculated at 28 GHz. Dispersion diagrams calculated for several values of the external biasing magnetic field show that, for some sets of ferrite and guide parameters and small values of the coupling spacing, only the even mode propagates. Also, the influence of the external biasing magnetic field on coupling coefficient is investigated. Relatively small changes in the values of the external biasing magnetic field can induce proper control of the coupling coefficient. The value of the dielectric constant of the region between ferrite slabs causes changes on the coupling coefficient, and can be used to tailor its value. In summary, the numerical results show that useful control of the coupling coefficient can be achieved by means of external biasing magnetic field.

Acknowledgment

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Comparison of Numerical Computation Results With Different Effective Dielectric Constants in Planar Structures

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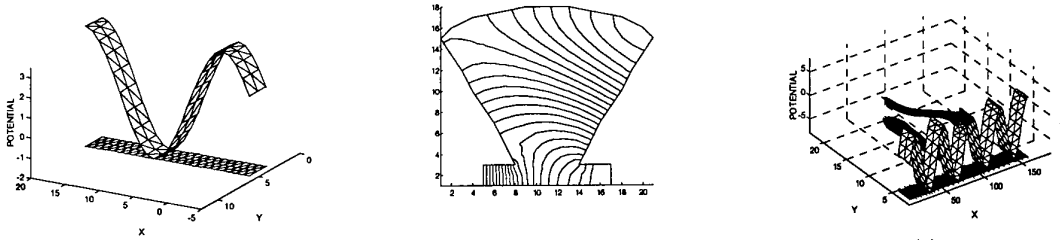
Microstrip is a very useful transmission line medium for implementation in distributed circuit designs at frequencies from a few gigahertz through some tens of gigahertz. Various analysis methods including analytical and numerical methods, full-wave numerical analysis and high frequency equivalent planar waveguide analysis have been introduced into engineering design. Among them, a reduced analysis model has been widely used where one or more significant approximations is employed to simplify the analysis domain as a two-dimensional problems. But the reduced analysis model has a limited accuracy and limited capacity to handle related problems such as mutual coupling, feed network effects, surface wave effects, and multilayer substrate configurations. This paper presents finite element method (FEM) based numerical analysis using a reduced analysis model for microstrip analysis. The numerical computation taking account of the different effective width and permittivity ε_{eff} are discussed in the paper.

The effective width of microstrip structures can be obtained by using an approximate formula, but for the arbitrary planar structures, the approximate formulas for the width of structures can not be easily obtained. An approximate formulas for microstrip radial stub have been developed by Giannini, et. al. As the different approximate formulas will result in different numerical solutions, the geometric structures calculated by those formulas will be very important for the reduced analysis model during the numerical computation.

The finite element analysis and visualisation results of time-harmonic electromagnetic are presented in following figures. In numerical simulation, both effective permittivity ε_{eff} and effective width are considered in the computation. A microstrip transmission line and a model of half of a shunt radial stub matching element in MMIC are shown in Fig.1 a-c respectively.



(a) (b) (c)

Fig. 1 a. Microstrip transmission line analysis by using FEM on MATLAB
(a) 3-D potential plot is calculated for 1.2 wavelength stripline,
(b) potential flux contour plot for the FEM model of 60° radial stub at 7GHz;
(c) 3-D plot of MMIC radial stub at 7GHz with extended stripline.

Session G14
Friday, July 17, AM 11:00-13:00
Room M
Optical Interconnections in Electronic Systems : Design and Realization (II)

Organiser : E. Griese
Chair : E. Griese

Design Issues for Three-Dimensional Optoelectronic Architectures

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Current manufacturing techniques result in essentially two-dimensional electronic systems. Individual chips are, and so are board level components. Although at the backplane level systems have a three-dimensional shape, they still are essentially two-dimensional from a system's point-of-view. Recent advances in optical interconnection technology provide us with the building blocks to extend these electronic systems into the third dimension. One particularly promising approach is the use of free space optical channels to interconnect parallel electronic boards, yielding three-dimensional optoelectronic processing systems. Although still in a developmental stage at the moment, this approach promises to be the key to new architectures for the future.

The advantages of enhancing electronic systems with optical technology in such a way are twofold. On one hand, introducing interconnections in the third dimension improves the topological properties of a system, reducing interconnect latency dramatically [1][2]. Calculations show that this is specifically the case for systems with complex interconnection structures, such as massively parallel processing systems [3]. On the other hand, introducing free space interconnections enables us to drastically reduce packaging-related bottlenecks in electronic systems. The most notorious of these bottlenecks is the pin limitation problem. It manifests itself on the chip level, where the number of required I/O-pads grows faster than the number available at the perimeter of a chip, as well as on the board level, where the number of signals entering or leaving an electronic board from the backplane is limited by the density of the connectors. Providing large numbers of free space interconnections distributed over the surface of the chips effectively reduces this bottleneck considerably [4].

Although optical interconnections have a high bandwidth, they may exhibit a relatively high latency due to the optoelectronic conversions in both transmitters and receivers. This means that, to use optical interconnections efficiently, we need to use latency hiding techniques such as pipelining or multirate design. These techniques achieve enhanced system performance by evenly spreading high latency interconnections over multiple clock cycles, enabling a higher clock frequency.

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Waveguide-based Optoelectronic Interconnects using Near IR EM Waves

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The development of advanced optical materials, which can focus, multiplex, transmit, modulate, receive, and demultiplex optical signals, will be key to the realization of economical and reliable wideband (~Thz) optoclectronic systems for optical signal processing and computing applications. A number of technology-related issues, however, currently impede further progress.

A myriad of polymer-based photonic devices aimed at optoelectronic interconnect applications have been successfully fabricated . These include high density linear and curved channel waveguide arrays, electrooptic modulator and modulator array, highly multiplexed waveguide holograms for wavelength division demultiplexing and optical interconnects, waveguide lens, and rare earth ion doped polymer waveguide amplifier. Issues related to CMOS compatibility will also be adressed.

Some of the applications based on the developed devices will be presented in the presentation.

Vertical-Cavity Surface-Emitting Laser Diode Arrays for Parallel Optical Interconnects within Multichip Modules

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Hybrid inter- or even intra-chip optoelectronic interconnects in microelectronic integrated systems may help to overcome the bottlenecks to further performance increases and miniaturization arising from conventional electrical interconnect schemes. Due to light emission perpendicular to the wafer surface, high efficiency operation at low driving currents [1], high speed modulation [2] and data transmission capabilities [3] even under bias-free operating conditions [4], and the possibility of forming high density 2D arrays, vertical-cavity surface-emitting lasers (VCSELs) are ideal transmitters for such optical interconnects.

We have designed and fabricated molecular beam epitaxially grown 4 x 8 bottom emitting VCSEL arrays for direct mounting on silicon integrated circuits. The VCSELs are based on a standard layer structure on GaAs substrate with the active region sandwiched between p-type top and n-type bottom distributed Bragg reflectors (DBRs). The active region contains three InGaAs/GaAs quantum wells for emission wavelengths of around 980 nm. Current and photon confinement is achieved by an oxide aperture in the top DBR, which is designed for low optical loss. Oxidation is performed after isolating the devices by dry mesa etching. In order to meet the requirements of 2D, high speed optical interconnects, each laser diode is supplied with two individual top contacts, the metalization scheme allowing flip-chip mounting the array modules junction-side down on silicon CMOS chips. The whole structure is planarized with polyimide resulting in a low extrinsic capacitance. Gold plating is used to connect the n-contact to the top side metalization. A non-wettable layer and wettable metal pads are necessary for the PbSn flip-chip solder bump process.

The VCSELs are arranged in arrays with 250 µm device pitch, offering high interconnect density at Gbit/s speed for each channel. 4 x 8 arrays with active diameters of around 10 µm have been characterized and show homogeneous characteristics. We have obtained threshold currents below 1 mA and threshold voltages of 1.5 V. Even at 1 mW continuous wave output power, which might be required for clock distribution, the driving voltage remains at 2 V and is thus fully compatible with advanced 3.3 V CMOS technology. High frequency measurements using a microwave probe show maximum small-signal modulation bandwidths of around 10 GHz, thus indicating data transmission capabilities of several Gbit/s for each element of the VCSEL array.

This work was supported by the EC under contract No. 22641 (OIIC).

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VCSEL Based Optical Interconnect Systems

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The rapid development of vertical cavity surface emitting laser diodes has made optical interconnects an attractive signal propagation modality for processor connections at the backplane level. Several companies are now marketing VCSEL based point-to-point fiber links for use in these applications. The next step in the development of optical interconnects will require more advanced optical systems with increased functionality and greater alignment tolerance. One approach to realize these requirements is to use free-space optics for localized high density connections and parallel fiber optic links for more distant connections. Alignment tolerances and cost factors can be improved if multimode fibers are used which have larger core diameters than single mode fibers. In this paper we discuss the issues related to interfacing free-space optical elements and multi-mode fiber optic arrays currently used with VCSEL based point-to-point links. The design considerations for coupling the temporally varying spatial field distribution from multi-mode VCSELs to free-space optical systems and fiber links are also presented. The design of a multiple data bus optical interconnect system is presented as an example which uses multi-mode VCSELs, multi-mode fiber arrays, and diffractive optical elements. The scaling rules to determine the number of processing nodes which can be connected with this configuration are also discussed.

A Finite Element Method with High-Order Hybrid Triangular Elements for the Analysis of Inhomogeneous, Lossy and Anisotropic Waveguides

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The finite element method (FEM) has been widely used in analysis and optimation of waveguide structures. For waveguides with a high grade of inhomogeneity the quasi-TEM analysis is no longer valid. Solving the vectorial equation leads to the difficulties that spurious solutions occur independent of the method which is applied. In the last years, it has been shown that if using edge elements spurious solution don't occur. Another advantage is that edge elements can handle fields at sharp edges, because the field components perpendicular to the edges can change abruptly.

To optimize microwave and optical waveguides it is very important to know the exact propagation constants and the field distributions belonging to them. For example, consider an electro-optic modulator where the local refraction index of the waveguide for the optical mode depends on the applied field distribution of the guided microwave. Because of that it is necessary to describe the geometry and materials in a very exact way.

The FEM with high-order hybrid elements has been applied to solve the double curl equation for inhomogeneous anisotropic and lossy waveguides in an efficient way. First order edge elements have been used to approximate the transversal field components, while node elements of second order have been used for the longitudinal field components. Compared with the conventional approach using the lowest order elements, this approach yields more accuracy.

In our implementation the material can vary linearly in a triangle finite element. As far as we know, our FEM approach is the first that can deal with such inhomogeneities. Application of the Galerkin procedure to the double curl equation of the magnetic field leads to a generalized linear eigenvalue equation. In most cases, only a few eigenvalues and eigenvectors are needed. We solved the final eigenvalue equation by applying the subspace iteration by Fernandez and Lu. In this method the sparse eigenvalue equation is transformed to a dense eigenvalue system of the order of interested eigenvalues so that all interesting solutions are achieved in the same step.

Analysis of Gradient Index Waveguide Lenses by Means of the Finite Element Method

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Gradient index lenses on planar optical waveguides are a class of mode-index lenses, which are the direct translation of bulk lenses to two-dimensional versions. Since mode-index lenses can perform the same functions as bulk lenses, they are key components for integrated optical devices.

Scattering from gradient index lenses may be analysed with the same methods as for the two-dimensional scattering from infinite long cylindrical bodies. For the latter problem various well known techniques have been developed, but only a few methods for the treatment of inhomogeneous dielectric cylinders are known. The most suitable method for the analysis of inhomogeneous bodies is the finite element method (FEM). To incorporate the Sommerfeld radiation condition in the finite element scheme the combination with the boundary element method (BEM) or transparent boundary conditions may be used. Due to the use of the BEM the governing matrices partly loose their sparsity. But the sparsity pattern and the band structure of the matrices are major advantages of the FEM. The use of transparent boundary conditions in contrast leads to sparse and banded matrices. Another disadvantage of the FEM-BEM combination is the occurence of spurious solutions.

This talk presents a finite element approach with a mixed hybrid formulation which is applicable to bodies of lossless and lossy dielectric materials with arbitrary magnitude of the refractive index. Transparent boundary conditions are used which are incorporated as inhomogeneous Dirichlet boundary conditions into the FEM scheme. The electric or magnetic field of the incidentwave is assumed to be polarized parallel to the axes of the cylinder. Instead of representing the electric or magnetic field as a scalar unknown an additional vector variable is defined. It allows the calculation of the Poynting vector and therefore the energy flux during the postprocessing without differentiation. The number of unknownsis not increased by the additional vector variable, because a static condensation per element during the preprocessing reduces the unknowns to three per triangular element.

Numerical calculations for homogeneous and inhomogeneous dielectric cylinders are presented. To verify the FEM results the scattering by lossless and lossy homogeneous circular cylinders are compared with known analytical results. As an example of a gradient index waveguide lens the Luneburg lens is investigated.

C-LAB is a joint research initiative of Siemens Nixdorf Informationssysteme AG
and Universitat-Gesamthochschule Paderborn

Session H09
Friday, July 17, AM 08:40-10:00
Room R02
Modelling Design of Millimeter Wave Antennas

Organisers : J. R. Mosig, A. Skrivervik
Chairs : J. R. Mosig, J. Citerne

Modeling of a Novel Planar Integrated (SUB) MMW Receiver by Using an Extended FDTD Method

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Elegant and compact designs of planar integrated submmW receivers are possible by using slot antennas and coplanar technology. These truly planar devices are based on a close interaction between non linear components (detectors or mixers), and passive elements (antennas, filters and transmission lines). The modeling of receivers are most important to obtain reliable designs, but a proper model has to handle both the complex structures in detail and the detector features.

Time domain algorithms are well suited for modeling non linear devices. In particular, Finite Difference Time Domain method is able to model jointly non linear devices and passive structures with a high degree of complexity. Schottky diodes and others detecting devices can be included in the FDTD method as non linear differential equations associated to a lumped circuit model. Voltages and current on the device can be related to the surrounding fields, so a simultaneous solution of the device and Maxwell equations is possible under a central finite difference scheme. Special stability requirements are needed for the extended FDTD algorithm.

To demonstrate the power of the method an analysis of an annular slot with all the auxiliary elements (feed/bias lines, air bridges), the FI filter and the model of a submmW schottky diode is presented. Experimental data on the diode is used to estimate the parameters of the non linear lumped circuit model. The results will show radiation patterns at RF and OL frequencies, currents and fields distributions on the structure, impedance analysis, and conversion loss estimation for the mixer. Future work is aimed to the modeling of arrays of integrated antennas and the modeling of active devices.

Simulation of Integrated Open Structure Receivers Using Improved Spectral Domain and Raytracing/Aaperture Field Integration Methods

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Integrated open structure receivers, consisting of a Schottky-diode mixer combined with a feeding antenna mounted on an extended hemispherical lens, are very promising candidates for future satellite-based remote sensing applications in the THz-region. Due to the increasing complexity of the concepts under discussion, a time- and cost-saving design and optimization of such structures requires the employment of sophisticated simulation tools.

For this goal we apply as a first step a full-wave Method of Moments approach using improved spectral domain analysis techniques for the circuit characterization and farfield computation within the lens. The utilization of rectangular nonuniform meshes and different kinds of basis functions allow a flexible modeling of both coplanar/slotline and microstrip circuits. Planar 3-D components like airbridges, via-holes and vertical interconnects are modeled with a volume current approach allowing a flexible simulation of bond wire structures as well as of thin, strip-like vertical interconnects using strongly asymmetrical basis functions. The method is extended at the moment to a general volume integral equation concept allowing the modeling of additional inhomogeneous dielectrics with finite extend embedded in multilayered media.

The crucial point of the developed approach lies in a very fast and accurate evaluation of the reaction integrals, which is achieved by a general asymptotic subtraction technique, allowing the determination of complete analytical solutions of the asymptotic system matrix for both the matrix entries concerning the planar parts of the structur as well as the entries related to vertical current components or polarization volume currents. With these techniques a fast and uniform convergence of the remaining spectral domain integrals is achieved even in the case of small structure components embedded in large circuit environments. Furthermore adaptive database techniques and redundance minimization algorithms are employed to minimize the computational effort of the remaining numerical integrations.

All integrations with respect to vertical current components or polarization volume currents are performed analytically in a preliminary step resulting in a small number of additional spectral domain representations providing the database for the simulation of an arbitrary number of possible vertical circuit or bounded dielectric components.

With the known current distribution on the circuit, in a second step the farfield within the lens is effectively determined with the help of the saddle point method. A subsequent raytracing approach allows to compute the field distribution on a planar reference aperture with the additional introduction of divergence factors determined with the help of a triangular meshing of the different apertures. This approach allows the consideration of further optical components and lens geometries. An aperture field integration finally provides the farfield of the whole integrated receiver. Since in general such a receiver is only a part of a larger quasioptical system and coupled to it with a Gaussian ray, the Gaussian coupling efficiency is of crucial importance for the performance of the overall system. Consequently we present a method based on the computed farfield distribution and a conjugate direction optimizer combined witha parabolic interpolation procedure, which allows the automatic adaptionof the Gaussian ray's beam waist and phase distribution for the best coupling efficiency. The developed methods are mainly demonstrated by means of coplanar mixer designs combined with ringslot antennas.

Influence of the Source Model on the Analysis of Slot Antennas in the Spectral Domain

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The geometric extension of the source is known to have an influence on input impedance modeling of printed antennas [1]. In the context of millimetric antennas design, the objective of this work is to establish the influence not only of the geometric extension but also of the description of the source domain currents or fields on the antenna analysis. The conclusions of such a work will give hints about the best way (in terms of accuracy versus time-efficiency) of taking into account hybrid components packaging or monolithic chips bonding in a printed antenna passive circuit model.

We shall present numerical results for the analysis of double-slot antennas electromagnetically fed by microstrip lines. The circuit is supposed to be surrounded by two semi-infinite dielectric half-spaces. Such a model is used to analyze antennas printed at the back of substrate-lenses [2]. The source is localized on the microstrip lines. Entire domain basis functions are used, except for the source domain, where discretization of the surface currents is performed.

The integral equations system is solved in the spectral domain, which gives a direct access to the far-field radiation patterns. Spatial fields and currents in the plane of the source are deduced from the spectral domain results, to evaluation the imput impedance of the antenna, at the access ports of the extended source domain.

A comparison with results obtained with delta-source models (used with either entire domain based or piece-wise sinusoidal basis function) and experimental results [3] will be presented.

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Cavity Effects on Printed Antenna Performance

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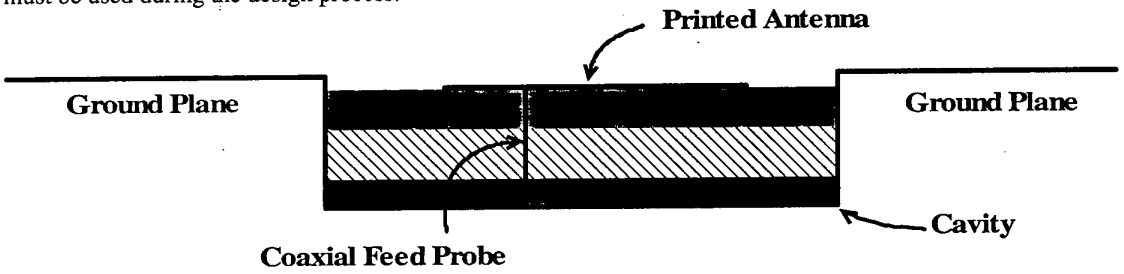
Advanced patch antenna arrays are sometimes fabricated with the radiating elements embedded in cavities as shown in Figure 1 below. This is done to minimize the mutual coupling between elements and to simplify fabrication since individual antenna tiles can constructed and arranged to form a large array. The antenna tiles may contain active circuitry, i.e. LNA's or switching circuitry, in addition to one or more radiating elements. The dielectric medium supporting the antenna element is, therefore, often stratified, as shown, to support the circuitry and radiating elements.

In this paper we will investigate the effects cavity side walls have on antenna element impedance and radiation performance. It is well known that as the cavity dimensions increase the effects become negligible. However, as the cavity dimensions approach the antenna element dimensions cavity effects must be taken into account. The cavity side walls will cause the resonant frequency and impedance locus to shift, and will deform the far field radiation pattern.

The cavity effects will be studied using a full-wave, moment method based, CAD tool. The simulation tool uses optimized mixed potential cavity Green's functions to model the electric and magnetic currents on the antenna element. Measurable antenna performance characteristics such as input impedance and far field patterns are calculated from the current distributions on the element and the aperture region above the element.

A simple coaxially fed antenna element in a rectangular cavity will be used as a baseline for this study. The cavity dimensions and antenna height will be varied. Design guidelines will be developed and presented to allow the determination of when an open region CAD tool is appropriate and when a tool that includes side wall effects must be used during the design process.



Session H10
Friday, July 17, AM 10:20-13:40
Room L
Dipole And Wire Antennas
Chairs : J. R. James, M. Drissi

A New Broad Band resistive wire Antenna for Ultra-Wide-Band Applications

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A new wide band antenna radiating short pulses has been designed at the CELAR and the I.R.C.O.M.. This wire antenna based on the TEM horn principle is shown in Figure 1.

The theoretical study antenna is carried out using a space-time « integral equation » (Miller, Poggio and Burke « An integro-differential equation technique for time domain analysis of thin wire structures ». J.Comp. Physics, USA (1973)). This rigorous method allows analysis of the current induced by the pulse generator on the wire antenna. The antenna is excited by gaussian or differential gaussian pulses (rise time < 300ps). The electric and magnetic fields are deduced from the knowledge of the currents on the wire structure.

Following the principle of the Wu-King non reflecting dipole, the geometrical details of the resistive load are varied to optimize the pulse radiation. Compared to the perfectly conducting wire antenna, the « optimized » resistive antenna has better characteristics :

- the temporally short wide-bandwith pulses are radiated with less pulse distortion,
- the input matching is better.

The performances of this Ultra-Wide-Band system have been « optimized » by adjusting geometrical parameters and compared to experimental measurements made on several antenna models (resistively loaded or not) :

- half antenna on ground plane,
- complete antenna in free space (anechoïc chamber).

Our optimisation showed good agreement with the results of these comparisons.

The antenna is expected to find many applications in topics such as target identification, burried object detection, etc... The first results obtained during experimentations in these two last applications will be presented.

Essential electromagnetic characteristics (300 MHz - 1 GHz) :

- input impedance : 200 Ω. A coaxial balun (50 Ω - 200 Ω) has been developped and realized in order to symetrise the generator impulse on the wires of the antenna and to maximise the feed power,
- TOS < 1,5 (100 MHz - 2 GHz),
- energetical values :
  - gain in the axial direction : 7dBi,
  - aperture angle : E plane : 45°,
  - aperture angle : H plane : 30°.
- pulse distortion : (< 1,35).

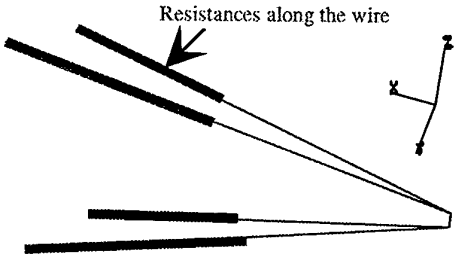

Figure 1 : Complete Antenna in free space

This work was supported by the « Centre d'Électronique de l'Armement de Rennes » (FRANCE).
The baluns and the complete antenna have been manufactured by the Europulse Company (Lot, FRANCE)

Excitation and Efficiency of Electrically small Plasma Antennas

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The effects of plasma sheaths on spacecraft communication antennas when re-entering the earth's atmosphere, have been exhaustively treated but recently the possible use of a plasma column as an antenna has also been proposed. [Gutman 1995, Kostrov 1995] This present paper investigates how this plasma antenna concept might be practically realised as a viable size-reduced antenna. Various conventional dielectric antenna configurations are first examined to establish how a cylindrical plasma column might be connected to the communication equipment and it is evident that the plasma excitation mechanism has to be an integral part of the antenna design.

In its simplest form the plasma is a lossless cylindrical column supporting axially symmetric surface waves. The associated transcendental equation is derived to determine the effect of the plasma frequency Ép on the resonant column length. It is confirmed that the antenna length can be arranged to be electrically small depending on Ép and that dipole-like radiation patterns characterise the terminal end aperture. Assuming that the collision frequency (is small, the same model is used to calculate the surface wave power loss and hence the antenna radiation efficiency.

Several possible methods of exciting the plasma column are identified such as probes and helical structures, illustrating that the surface wave launching process necessitates an unwanted radiation loss. The latter is estimated for an aperture launcher and this additional loss mechanism leads to conflicting design constraints. According to this idealised model it is feasible to design an efficient electrically small antenna over a narrow range of Ép and (but the practical realisability relies on first, whether or not a suitable plasma can be generated and second, a means of accommodating the electrodes, glass tube and power supplies so that the antenna action is not affected. In conclusion, the practical requirements are illustrated by measurements on a commercially available florescent light tube at UHF frequencies.

Comparative Methods of Solution for Input Impedance Characteristics of Truncated Conical Dipole by MOMENT Method and HALLEN Integral Equation

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Harrington and Pozar have done extensive work for calculating the input impedance of dipoles by means of moment method.In Pozar's work problem sensitive has been taken by means of rigorous integral technique.In the present work of the authors calculation of input impedance of truncated conical dipole by means of the moment method has been done.This involves consideration of more careful basis function for the sensitive feedpoint compared to that of the work of Pozar.

Calculations of the input impedanceof the conical dipole as per Schelkun off equation are in agreement with the experimental results within 25% of accuracy.

After comparative study of calculations by Scelkunoff equations and moment method theoretical results are compared with experimental results for input impedances of different sections of the truncated conical dipoles of an arbitrary cone angle.Theoretical resultsare also compared as calculated by Hallen integral equation.

Work in progress for finding out the optimum angle and truncating section for wideband response of the proposed truncated dipole.

Theory of Biconical Dipole Antennas

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The biconical antennas, as the band antennas, take the extremely important place in the general theory of wide-band antennas. However to the present time, in the literature known to us, approximate methods of a solution of the integro-differential equations of the biconical antennas are developed only. They do not allow to take into account the real geometry of antennas.

And it is connected, on our sight, that the integro-differential equations of these antennas are more general, more complicated, than equations of other types of dipole antennas both with a theoretical, and with a computing point of view.

Theory of the integro-differential equations of the present antennas is developed. The theorem of an existence and of an uniquenesses are proved. An effective method of a solution of the integro-differential equations is constructed. The results of the numerical calculations are considered.

Band Properties of Dipole Antennas Near to Ground

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The report is devoted to the analysis of dipole antennas, located near to the boundary of division of mediums perpendicular and in parallel last. The vibrators are excited by an axisymmetrical field. The theory of the integro-differential equations of the present antennas is developed. The theorem of an existence and of an uniquenesses are proved. An effective numerical - analytical method of a solution of the integro-differential equations is constructed. The high effectiveness of a method is demonstrated. Band properties of dipole antennas, located near to the boundary of division of mediums, depending on geometric sizes of an antenna, parameters of a medium and sources of excitation, are investigated.

The Synthesis of the Linear Continuous Antennas with Patterns without Side Lobes

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The problem of the synthesis of linear continuous antenna with ños$^N(\pi/2\sin\theta)$ pattern form which hasn't side lobes is discussed. The problem is solved with method of partial patterns, the form of which is $Sn(z)=[\sin\pi(z-n)]/\pi(z-n)$, with help of the determination of minimum value of the maximum of the difference between synthesized pattern and required one. The synthesized pattern is represented in form of partial patterns series $R^*(z)=\sum_{-\infty}^{+\infty} R^*(n)Sn(z)$. The current distribution ensuring pattern R*(z) is determined from $f(y)=\sum_{-m}^{m} U_m(n)P_k(n)\exp(-iny)$, where $U_m(z)=\frac{\sin(\pi z)}{\pi z}\Big/\prod_{k=1}^{m}(1-z^2/k^2)$ and the antenna length is given at a wavelength.

The numerous calculations of amplitude-and-phase distribution of field sources in the antenna by variation of power index N and, therefore, by the variation of the antenna directivity in wide bounds had been carried out.Besides, the antenna length can be variated for each N from very small values (parts of wavelength) to very big (at least bigger than the antenna length with the constant amplitude- and-phase distribution of sources, ensuring the same pattern main lobe as synthesized antenna). In the capacity of variable parameter in the calculations the index of polynom, approximating required pattern, was chosen. The synthesized pattern was calculated on the obtained sources distribution and then it was compared with required pattern at all the observation space.

The analysis of the calculations showed the synthesis of the small size linear antenna with the pattern without side lobes leads to classical effects of the superdirectivity when the amplitude-and-phase distribution has oscillating character with changing sign of phase, especially in the case of very short antennas. It was shown that the presence of small side lobes in the required pattern decreases superdirectivity effects (i.e. maximum current values in the antenna is decreased).

Also the computer analysis of stability of the synthesized pattern have been carried out. With the purpose of such analysis the obtained sources distribution was distorted at random (with uniform law of errors distribution) at the beforehand given limits. It was shown the longer linear antenna the bigger changing current values in the sinthesized antenna ensures the pattern which is acceptable for practice. Under these counditions the antenna works at more wide frequency band.

Also the synthesis of linear antennas with gaussian form pattern without side lobes had been considered.

Experimental Proof that dc Field Sensor Operation Conforms with Antenna Theory

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It is usually understood that sensors for measuring ac fields, even at low frequencies, can be described by circuit models similar to those applied in antenna theory. We have recently demonstrated, that related models are of value even in treating dc field sensors [1]. The latter models interpret the sensors operation by relying on the effect of their time varying series capacitance. Most of the previous authors regarded the mechanical variability of dc field sensors (such as the covering fieldmill) as causing periodic chopping of the displacement-vector-flux. The main achievement of the present work is in proving experimentally that the effect of the time - varying series capacitance is the actual contributor to the coupling of the most common dc field sensors to the field sources. The proof is attained by devising a new sensor, where there is no apparent chopping operation involved in its movement. The mechanical movement there does not cause a shutter or vanes to be opened and closed periodically. The only effect of the mechanical movement in the new sensor is in varying series capacitance that couples the sensor to the field sources. This is achieved by changing periodically the length of the sensor elements. (The new sensor is realized as a time varying dipole). It is shown, that the new sensor in spite of the fact, that its performance does not involve any quasi - chopping mechanism, is nevertheless capable of sensing dc fields. Furthermore, the measurements results conform with the quantitative theory suggested by the authors.

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Mathematical Model of Strip Dipole Antenna on Stratified Substructure

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The paper describes the generalization of a thin wire antennas integral equation for a curved strip dipole antenna on a stratified substructure. On the basis of the equivalent parameters method is shown the equivalence of the models to a strip dipole antenna on plane layers or to an insulated tubular antenna in axially symmetric stratified medium. The approximation of a long line theory results in formulas for a wave characteristic impedance of a strip dipole antenna on the stratified substructure and reveals the sinusoidal character of a current distribution function. The examined structure dispersion equation is also derived and solved. On the basis of the self-congruent linearization method in [1] the mathematical model of isolated linear antenna has been derived. This model is based on the self-congruent integral equation of the first kind for vector magnetic potential, known as Hallen's type equation

$$\int_{-L}^{L} \frac{I(s')}{4\pi} G_j(s,s')ds' + C\cos k_L\left(s-\frac{d}{2}\right) = \frac{iV_0}{2\omega\mu} k_L \begin{cases} \sin\left(k_L\left(|s|-\frac{d}{2}\right)\right), & \text{when } \frac{d}{2} \le |s| \le L \\ 0, & \text{when } |s| \le \frac{d}{2} \end{cases} \qquad (1)$$

where I(s') is an unknown function of a current distribution, the equivalent constant of propagation k_L is found from the solution of the transcendental equation [1], V_0 and d are the voltage applied and the feeder area size, respectively. A right-hand part of the equation (1) takes into consideration the size of feeder area between the conductors of a dipole radiator. It is clear that when $d \to 0$ the right-hand part of the equation (1) defines a delta-function source [2]. In [3] has been noted the invariance of the integral equation (1) with respect to the interface geometry and has been carried out a extension of this equation to the plane interface of media. In [4] it has been shown that if the curved dipole radiator is on a coplanar plane with the interface then the vector self-congruent integral equation in the curvilinear system coordinate connected with the dipole radiator becomes the scalar equation. The model on the basis of equation (1) with the equivalent parameters from [1,5] defines the current distribution function along the strip dipole radiator on the stratified half-space which consists of number M layers. P layers are at a relatively short distance from the half-space interface and other (M-P) layers are relatively far from the half-space interface. Therefore the field from P layers is found by the equivalent constant of propagation method and the influence of (M-P) layers is realized in approximation of the reflection coefficient method.

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Input Impedance of Loaded Wire Antenna in the Presence of a Lossy Half-Space

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The finite element/exponential approximation procedure is developed for loaded wire antenna. It provides the simple and efficient technique for input impedance calculation.

The finite element/exponential approximation solution

The electric field integral equation (EFIE) for lossy half-space problems [1] is solved via the combination of a variational and projective approach of finite elements (FE), [2]. Atenuation terms in the form of Sommerfeld integrals, appearing in the EFIE kernel, are evaluated by using the exponential approximation technique. Combining the functional of input impedance and the proposed FE procedure the input impedance is calculated from the following matrix equation :

$$Z_{in} = \{\alpha\}^T [A] \{\alpha\}^* , \quad [A] = \sum_{i=1}^{M} [a]_{ji} , \quad j = 1,2,\ldots,M \tag{1}$$

where [A] is the generalized mutual impedance matrix (global FE matrix) which is assembled from the appropriate local FE matrices $[a]_{ji}$ and M is the total number of elements. This algorithm is convenient for calculating the loaded antenna impedance, regardless of one deals with homogeneous or inhomogeneous media. The input impedance spectrum for resistively loaded dipole antenna over a lossy half-space with radius a=0.05m, length 2L=10m, height over ground h=3m, and e_r=40 and s=0.001mhos/m is presented in fig.1.

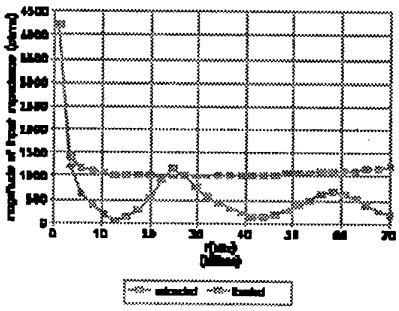

Fig. 1. Input impedance magnitude for horizontal dipole

The suggested method shows advantages over the widely used point matching techniques and it can be easily extended to more complex geometries and material properties.

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J. I. P. R. 4 - Session I09
Friday, July 17, AM 08:40-12:20
Room 200
Joint European Community-Commonwealth of Independant States
EC-CIS Polarimetry Projects

Organisers : L. Ligthart and V.N. Tatarinov
Chairs : L. Ligthart and V.N. Tatarinov

Polarization Properties of Distributed Radar Targets

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At present, in most cases, the radar object is considered to be the point object. However, this idealization obstructs the further development of both theoretical and experimental methods for the radar objects detection, selection and classification. In practic the radar backscattering is the result of the waves diffraction on the object observed. Depending on the object shape, its dimensions, the smoothness degree and other characteristics the main scattering processes are determining a polarization properties of non-point objects.

Both the space spectrum of the diffracted field and a space spectrum of polarization parameters (include a space spectrum of scattering operators) for some cases of non-point radar objects are considered in the paper.

Averaging of Polarization-Frequency Properties of Random Complex Radar Objects. Description of the Fine Structure of Polarization Speckle

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A polarization properties of the scattered field for complex radar objects are characterized by the complicated interference structure. It is connected with the space coherence of illuminated signal. There is complicated image of polarization speckle-effect in this case. A method of frequence averaging is providing for the statistical regularity of polarization parameters descriptions. A data both theoretical and experimental investigations of averaging method's forpolarization speckle-effect are cosidered in the paper.

At present, in most cases , the radar object is considered to be point object. However, this idealization obstructs the further development of both theoretical and experimental methods for the radar objects 'detection, selection and classification. In practic the radar backscattering is the result of the waves' diffraction on the radar object observed. Depending on the object shape, its dimensions, the smoothness degree and other characteristics the main scattering processes are determining a polarization properties of non-point objects. Both the space spectrum of the diffracted field and a space spectrum of polarization parameters (include a space spectrum of scattering operators) for some cases of non-point radar objects are considered in the paper.

Polarization Properties of Complex Radar Objects Having Random Distribution of the Scattering Centers

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In practice, the large-size radar object, whose surface's curvature is changed along their extent (aircrafts, ships, cars and so on), can be presented as the aggregate of the rigidly connected scattering centers ("bright points"). The changing of the object surface's material and curvature leads to the changing of the polarization properties of the scattering centres. For such radar objects both orthohonal components and polarization ratio of scattered field are characterized by the complicated interference structure and a large value of the so called "flickering index".

There are two problems of statistical description of polarization speckle-effect :

- Problem of statistical model selecrion's;
- Problem of averaging way selection's;

The latter problem is connected with impossibility of the use of ergodicity hypothesis.

A data both theoretical and experimental investigations of nonergodicity polarization speckle-effect are considered in this paper.

Doppler-Polarimetric Radar Measurements of Precipitation

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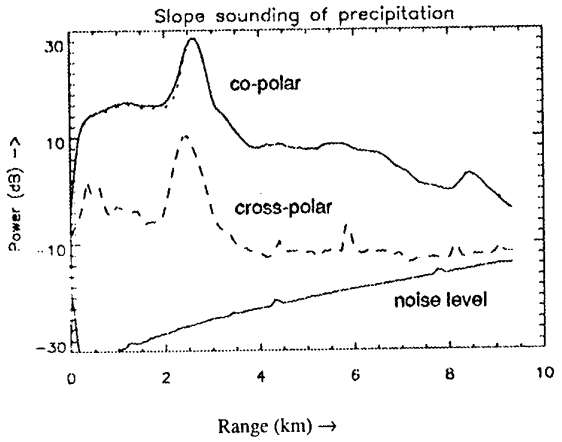
Doppler-polarimetric radar measurements of precipitation are performed at the Delft University of Technology with a roof-based FM-CW polarimetric radar operating at S-band. At this radar frequency, the absorption and backscattering by rain are small. Backscattering profiles of the troposphere are measured using a large transmit power, 10 and 100 Watts, respectively, for rain and cloud studies. Attention is given to four topics : polarimetric calibration, signal processing, measurement interpretation and search for new methods to discriminate different types of hydrometeors, or hydrometeors from clutter when the radar does not point to the zenith.

Precipitation has been already polarimetrically using incoherent processing. The two following polarimetric parameters are generally investigated : the differential reflectivity Z_{dr} and the linear depolarization ratio L_{dr}. Here, the attempt is one hand to obtain simultaneously the Doppler and polarimetric information and on the other hand to get the complete polarimetric description of the precipitation. The aim is a coherent processing, resulting in a time series of scattering matrices per Doppler and range cells.



Real-time software is available to acquire range spectra or the scattering matrix per range and Doppler cell. But improvement of the signal processing is still going on. The timeaveraged power of range spectra is given above as a measurement example. Two linear orthogonal polarizations have been used for this measurement, resulting in two co-polar and one cross-polar range spectrum. The radar elevation is 30 degrees. The main peak represents the melting layer where snow particles are melting into rain drops. The radar receiver contains a 6 dB per octave amplifier which corrects for propagation losses in the case of volume scattering but increases the noise level as a function of range.

This paper is going to present the obtained Doppler-polarimetric measurements of precipitation. The target analysis is going to be secondary and focus will be given to calibration and signal processing aspects.

Theoretical Modeling of Microwave Scattering, Polarimetric Method and Visualizing Permittivity Characteristics of Earth surface

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In microwave scattering the electromagnetic field and its characteristics are the sources of information which allow us to classify the researched object. The contents of this report is the formulation of microwave scattering. The generalized problem of monitoring the environment with radar is described abd can be resolved successfully under the condition that more information is extracted from radar measurements. This additional information can be obtained for example by the use of radar pjlarimetry.

This report consists different parts:

1. Diagnoshcs of the environment using Polarimetric Radar Monitoring: Formulations and Potentials ;
2. The problem of radio wave reflection from vegetation ;
3. Se,attering of waves by a layer with a rough boundary ;
4. Mathematical modeling for randomly non-homogeneous media ;
5. Reflection of electromagnetic waves from non-uniform layered structure ;
6. Radiowave reflectionfrom structures with internal ruptures.

These materials consists such well-known results, as an absolute original results for receiving whole picture of modern state problem "Microwave scattering". Most tasks are described in this report must be researched far. Possible ways solving these task's are described too.

In the paper full attention is paid to a polarimetric method used the determination of the earth surface electrodynamic characteristics (the complex dielectric permittivity). Specific for the method is that only relative measurements of signals in channels, orthogonal in polarizarion, developed by authors, are needed. The approch, is presented as a new method of geometrical visualization of these surfaces.

This method permits to construct a special sphere (KLL-sphere) where each point of this sphere unambiguously displays some type of earth surface. The distinction in different ground types is based on distinction in real and imaginary parts of the complex dielectric permittivity (real dielectric constant and conductivity). KLL-sphere properties are investigated by a change in basis polarizations which are used in measurements and by taking the angle of incidence of the radar wave to the ground into consideration.

It should be emphasized that the basic significance in the new method is played by the irregular behaviour. The change in angle of incidence enables us in an essential way to increase the reliability in discriminating the different earth surface types. It opens basically new opportunities for solving problems in the field of earth surfaces classification and identification.

It is shown that as the earth surface « image » on the KLL-sphere changes, it means at the same time a change of the earth surface physically and chemical characteristics (salinity, humidity, temperature etc.).

The received results are widely illustrate by particular surfaces and by numerical results. The results obtained so far, can be used only to display the various types of earth surfaces, they can also be applied in problems of ecological monitoring, at classification (including the volumetric permittivity characterization) of agricultural crops, forestry files etc. in complete volume. These results can appear useful for solving inverse problems.

IRCTR Activities in Modeling of Electromagnetic Wave Transmission Through Air-Ground Interface

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Electromagnetic wave scattering from natural surfaces has been treated intensively during last 40 years. Mainly radar and bistatic cross-sections of the surfaces have been investigated. Wave transmission through rough interface and the polarimetric characteristics of scattered and transmitted fields have not been studied with the same completeness as the angular distribution of scattered field energy. Nowadays IRCTR performs intensive studies of these phenomena in the framework of its Ground Penetrating Radar program. These IRCTR's activities are described in the presentation.

Typical frequencies of electromagnetic waves in GPR applications are within the range from 20MHz till 2GHz. For such frequencies the surface roughness can be considered as small or comparable with the wavelength. Due to this condition two perturbation approaches have been chosen for electromagnetic modeling.

The first approach is the statistical perturbation theory. Here the original boundary problem of electrodynamics with a rough interface between air and ground is transformed to the equivalent problem with a plane interface and perturbed boundary conditions. A statistical averaging is applied to resulting problem and equivalent boundary conditions are derived for the averaged field at the plane interface. The equivalent boundary conditions take into account multiple scattering from roughness. The region of validity of these conditions is far beyond usual small perturbation limits. The analytical expressions for the mean intensity of the noncoherent component and the coherent transmission coefficients for vertically and horizontally polarised plane waves are derived.

The second approach is based on Monte-Carlo method. Random one-dimensional interface with given statistical properties is generated numerically. The initial boundary-value problem is reduced to the set of two simultaneous integral equations, which is solved with the unified perturbation method for each realisation of the random interface. Averaging over 50 realisation of random interface is used to calculate the intensity of coherent and noncoherent components of the field.

Using both approaches typical GPR scenarios are simulated. Because typical correlation functions for the natural surfaces are not known exactly, the correlation functions with Gaussian and power law spectrums have been used. The energy transmitted into the ground for both vertically and horizontally polarised plane waves and the input impedance of the ground are calculated as functions of dielectric permittivity, operating frequency, incident angle and corrugation's parameters.

The modeling of electromagnetic wave transmission through air-ground interface provides a better understanding in the phenomena encountered in subsurface testing. We aim to integrate the corresponding software into a practical GPR system to enhance its performance. Another directions of the future work (comparison theoretical results with experiment, etc.) will be also discussed in the presentation.

Joint Russian - French project : One-Channel Surveillance Multiparametric Polarization-Radar for Experimental Investigations, Rejection Comb Filtering as Method of Polarization Invariants Measurements for Surveillance Polarization Radar

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It is known that using of the electromagnetic wave polarization parameters in radar is caused by necessity to improve radar's characteristics and informative abilities. A development both a theory and an engineering of polarization radars is not possible without experimental investigations of radar targets polarization properties. A polarization radar for experimental investigations must be able to measure, register and image in real time scal certain polarization parameters and energetical parameter of radar objects simultaneouslly with the object's. A theory of this radar must be able to explain methods of experimental data interpretation's both for point and for distributed radar targets. The development of polarization radar for experimental investigations is the main task of the collaboration between Laboratory RES (Russia) and Laboratory SEI (France).

This radarwill measure the following (both invariant and non-invariant) of radar target scattering operator's:

1. A module of complex degree of polarization anisotropy;
2. A real part of complex degree of polarization anisotropy;
3. Full radar cross-section;
4. An angle of mutual orientation between eigen polarization basis of radar taeget and polarization basis of radar. Parameters 1, 2, 3 are invariants, parameter 4 is dinamic value (non invariant).

Russian polarization small-scal surveillance radar "Polaris" (Lab. RES) and French DSP-acquisition station (Lab. SEI) take as a principle of new radar The main stages of joint Russian-French polarization radar development's are considered in the paper.

A surveillance polarization radar must be able to measure and image in real time polarization-energetical parameters of radar objects with the object's coordinates for all distances. It is necessary, a technological capability to find for the measurement of radar targets polarization invariants. It is possible, this technological capability represent with the use of rejection comb filtering method's for radars, having a modulation of radiated waves polarization's. A physical ground for the use of this method is a fact of equivalence of polarization processing structures to structures of rejection filters used in moving target indicators. However, the use of polarization modulation allows to discriminate stationary small-scale targets. Theoretical results confirms with the use of experimental data.

Scattering Matrix Radar Parameter : The One-Channel Polarization Radar Theory

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In this paper, transformation of a transmitted signal's polarization structure is considered for one of the most informative one-channel polarization radar. Formalism of matrixes and vectors of Jones was used.

It is shown, that in case of a rotating linear polarization signal it is possible to differ information about scattering matrix's parameters of a radar object. In this case, angle of a linear polarized E-vector is turning from pulse to pulse of the transmitted signal.

Extremes of a received signal's envelope was found for various combinations of the $\rho(\mu)$, Θ and $\Delta\varphi$ parameters of the radar target's scattering matrix.

Methods of measurement of the ρ, Θ and $\Delta\varphi$ parameters for radar imaging are determined.

Interpretation of the polarization parameters was made. It is shown that availability and range of values of the polarization parameters can be used for effective selection of a radar objects.

In this paper results of a theoretical analysis and experimental dates are presented.

In this paper, results of analysis of a scattering matrix form for various radar objects are presented. It is shown that in the most cases the scattering matrix may be represents by few parameters: ρ - electrical form factor (or μ - polarization anisotropy degree); Θ - orientation angle of target's eigenbasis; $\Delta\varphi$ - additional phase shift between orthogonal components of a received wave.

It is shown that experimental estimates of the electrical form factor are agreed with correspondent values of the geometrical form factor for radar objects with geometrical sizes smaller than wavelength (rain drops, snow flakes, hailstones and etc.). Orientation angle of target eigenbasis of this objects is agreed with their geometrical orientation too.

It is shown that the scattering matrix of radar objects with geometrical sizes bigger than wavelength may be represents by the scattering matrixes of the dihedral and trihedral corner reflectors. In this case parameters ρ, μ and $\Delta\varphi$ are depended on ratio of effective cross sections this reflectors and space distance between there phase scattering centers. Orientation angle of the target's eigenbasis of such object is determined by geometrical orientation of a dihedral corner reflector's rib.

Parameters of this scattering matrix form can be measured by one-channel polarization radar. Estimates and variations of this parameters are differed for various types of radar targets.

Session J10
Friday, July 17, AM 08:40-11:40
Room 450
Classification of Synthetic Aperture Radar Images

Organiser : S. Quegan
Chairs : S. Quegan, C. J. Oliver

Information from SAR texture

Chris Oliver,
DERA, Malvern.

The use of SAR texture to classify rain forest into primary and secondary categories has been demonstrated. Primary rain forest contains dominant individual trees which rise well above the surrounding canopy, whereas secondary forest (with regrowth) is much more uniform. If the returns from the tree crowns in primary forest are resolved from their associated shadows, strong texture will be visible in the image which can be exploited for classification.

This contribution addresses a variety of questions in the search for optimised approaches to classifying forest texture. Initially we consider what texture measure contains the information optimally and relate this to the model for the PDF of the underlying RCS. An optimised texture measure then provides visible differentiation between classes. If we introduce a model which asserts that the texture within a neighbourhood is correlated, the uncertainty due to speckle can be further reduced using global optimisation (based on simulated annealing).

Another approach is to introduce a cartoon model which asserts that the texture is made up of regions of uniform texture measure. What is required is a solution to the position and strengths of these regions. Texture segmentation techniques can be developed which can either be model-based or provide a global optimum solution in a Bayesian (Maximum Likelihood) sense, given the texture PDF. We develop these models and apply them to the texture segmentation of Brazilian rain forest images. In these examples the number of regions is entirely data-driven and is determined by the errors with which the texture measures can be estimated. An alternative is to specify the number of different classes of texture measure and determine their positions.

An important practical consideration is whether satellite systems, such as ERS-1 or Radarsat, offer sufficient resolution to provide adequate texture information. We show that ERS-1 should be barely adequate if operated in the roll-tilt mode but that Radarsat is satisfactory in the fine beam mode.

A Rigorous Analysis of the Information Content of ERS - SAR Images

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Introduction

Today's operational spaceborne SAR Systems are configured with one wavelength and one polarisation only. The resolution is in the order of tens of meters and image quality is degraded by the speckle effect. In order discriminate between different land cover types it is necessary to use all the information carried with the backscatter signal. Typically the mean of a ROI is used. But it was shown by several authors that texture can improve the classification results. It exists a well known theory of pure speckle based on the random walk yielding a mathematical description of first order and second order statistics. For linear detection first order statistics are described by the Rayleigh distribution. For the description of texture the K-distribution often is used. Second order statistics usually are described by the power spectrum. Phase is usually neglected when satellite data is investigated.

Procedures

Single look complex data (SLC) of ERS - SAR images yield a resolution of 5 x 25 meters. First order statistics is for agricultural land use well described by the Rayleigh speckle model. But deviations, if existant, can be measured by statistical tests. The author used the following tests:

2. Moment
3. Moment
4. Moment

Kolmogorov - Smirnov Test
Chi - square - test

These deviations are existing systematically yielding additional information on the crops.

Forest and urban areas are more likely to be described by the K - Distribution yielding two degrees of freedom.

Also the phase carries some information that is hardly visible by the eye but can yet be detected and helpful in land cover classification.

Supervised vs. Unsupervised interpretation of polarimetric SAR imagery using model regularization

Paul C. Smits, Silvana Dellepiane

In real world remote-sensing applications there are many situations in which the natural classes in an image do not correspond to the classes that the end-user is interested in (Lillesand and Kiefer, 1987). In fact, in most daily image classification tasks, the process of classification is far from fully automatic but, being hybrid, relies on both manual and automatic interpretation. In the feature space which is set-up with appropriate features, the user identifies the natural classes, possibly using tools like, for instance, the K-means approach, and relates to them appropriate image class labels, sometimes being forced to assign groups of real-world classes to one label (Schowengerdt, 1997). Obviously, this determines strongly the usefulness of the remote-sensing system for the application at hand and influences to what extent the user's objectives will be fulfilled.

In Synthetic Aperture Radar (SAR) image interpretation, where at times one has available only the intensity image of a single band (e.g., L or X band), obvious restrictions apply on the number of phenomena that can be distinguished. Moreover, the speckle noise, typical for SAR,does not make the classification task easier. Specific statistical models should be applied to account for the nature of the data (see, for instance, (Beauchemin et al., 1996), (Lopes et al., 1990), and (Ulaby et al., 1987)), and exploiting explicitly spatial information on the level of image class labels has proven to help the classification a lot (Rinot and Chellappa, 1993; Smits and Dellepiane, 1997).

A remaining problem is the training of image class models. Although supervised classifiers are preferred for their accuracy (or rather for their capability to say something valid, a priori, about the classification accuracy), there are many applications that require some form of unsupervised training, due, for instance, to the costs of training samples, or to the fact that one wants to analyse regions which ground information is impossible to obtain.

In this article we focus on the differences between supervised and unsupervised training of polarimetric SAR imagery, applying a MRF region label model. An energy function is defined like in (Rignot and Chellappa, 1992) that utilises on the one hand the correlation between the intensity images of the different polarizations (in this paper HH and VV of the Flevoland, NL, scene), and on the other hand a smoothness prior defined in a region label model. We study the behaviour of the simple 2-D (HH-VV) feature space both in a supervised case (training based on ground information) and in an unsupervised case (using the K-means algorithm). The particularity of the present paper is that it provides insight in the behaviour of the feature space under spatial regularization for both supervised and unsupervised cases.

Both numerical (class confusion matrices) and visual results are reported for the Flevoland scene containing agricultural sites. Images of the feature space show differences and correspondences between the supervised and the unsupervised cases. It is concluded that the supervised and unsupervised approaches have both right of existence from the accuracy point of view (kappa (Stehman, 1996) values over 0.8 are measured for both), but that the effective use depends on the objectives of the end-user.

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Supervized classification of targets in alpine terrain based on multiparameter SAR data

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Polarimetric multifrequency data offer the possibility to calculate several parameters for each resolution element. In alpine terrain some of the commonly used polarimetric measures, the co- and cross-polarized backscattering coefficients, have strong variations with the incidence angle. In order to reduce this dependence ratios between backscattering coefficients are calculated. Selected ratios and the magnitude of the HHVV correlation coefficient are the components of the multidimensional feature vector. The angular dependence of these parameters can not be completely eliminated but is less pronounced than for single backscattering coefficients.

Two classification procedures are presented. In the maximum likelihood classification (MLC) the discriminant function is based on the assumption of normal statistics. Training data are used to generate the spectral signatures required as input for the classification. The results can be tuned through three parameters: the option whether pixels can be assigned to the null class, the Gaussian feature space threshold and the relative a priori probability for each class. The sensitivity study of MLC reveals that if the null class is allowed the a priori probability has a weak influence on the classification result, whereas by increasing the class threshold the number of unclassified pixels can be reduced. The second procedure is based on the average backscattering signatures of the components of the feature vector. The classes are successively separated by applying decision rules which take the incidence angle dependence of the polarimetric parameters into account.

The algorithms were applied on SIR-C/X-SAR data of the high alpine test site Oetztal, Austria. Because the signatures of ice and moraines are similar in SAR data the segmentation of glaciers and ice-free areas is performed using high resolution optical data. On the glaciers the classification is reduced to a two class problem, accumulation and ice areas. On the unglaciated areas 4 surface classes must be separated: bare soil, forest, dense and sparse short vegetation. The performance of the classification algorithms is estimated through comparison with field observations and with a Landsat TM classification. The best agreement with field observations is observed for hierarchical classification results on two of the main glaciers in the site. The separation between classes with similar roughness (e.g. bare soil and short vegetation) is very weak at microwave frequencies.

Segmentation of multitemporal data may provide better classification results than procedures based on single term data. The ratio between backscattering coefficients acquired at the same polarization, frequency and imaging geometry ensures optimum correction of incidence angle effects. Targets with large temporal variations of backscattering, like snow and ice, can be well classified through this procedure.

Fuzzy C-means segmentation of land-covers in interferometric SAR images

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Interferometric SAR images carry different types of information, the instantaneous values of radar backscatter, the short term variations as described by the coherence and the long term variations as obtained from multi temporal images. Several problems have to be assessed in order to classify and segment different land covers. There have to be models for understanding the information contents, which can vary temporally and spatially (especially in mountainous areas) and be obscured by different kinds of noise. The basic information content in SAR and In SAR images is relatively well understood in many cases, including topographic influences. Moreover, sophisticated speckle filters can almost fully remove the speckle noise. The noise in the coherence image depends on the coherence estimation technique applied and so far no model-based noise filters have been developed for any kind of coherence estimation technique. Principal components analysis is a good technique for separating stable and variable signatures (in time that is, ERS SAR images only acquire one channel, C-band VV, at every overpass), and the only drawback is that the actual transformation applied to the data, depends on the data itself. In other words, a principal components tranformation varies with the input images.

However, a principal components transformation has two major advantages; it concentrates the information of the input data to the first components and it can reduce noise. Using the fuzzy C means clustering technique can cope with many of the above problems. Nevertheless, it is often preferred to "clean" (i.e. optimized speckle filtering and coherence image nosie filtering) all input images before any clustering. Moreover, the fuzzy C-means clustering technique requires fast computers with large disk space. The computing time of the fuzzy C-means clustering technique is largely dependent on the number of input channels (images) and by using a principal components transformation it is possible to considerably decrease the number of input channels. In essence, this paper presents a whole processing scheme to go from SLC SAR images to a classified (or segmented) product. The scheme basically consists of InSAR processing, noise filtering of the images, principal components transformation and a fuzzy C-means clustering technique. The noise filtering consists of a Gamma MAP speckle filter for SAR intensity images and a median filter for InSAR coherence images. The overall aim has been to have a data-driven processing scheme, i.e. a mainly unsupervised algorithm. Results are mainly intended for the case of boreal forest mapping but are also relevant for the case of land-cover classification.

UNSUPERVIZED CLASSIFICATION SCHEME AND TOPOGRAPHY DERIVATION OF POLSAR DATA BASED ON THE « H / A / $\underline{\alpha}$ » POLARIMETRIC DECOMPOSITION THEOREM.

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Classification of Earth terrain components within a full polarimetric SAR image is one of the many important applications of Radar Polarimetry. In this paper we consider the use of multi-polarisation data for quantitative remote sensing applications and the role polarimetric observables play in relating the two key elements of measurement and physical modelling in polarimetric systems.

We propose a method for extracting average parameters from experimental data using a smoothing algorithm based on second order statistics. This method does not rely on the assumption of a particular underlying statistical distribution and so is free of the physical constraints imposed by such multivariate models. For example, the multivariate Gaussian distribution is popular because of the ease of analytical development of moments and marginal distributions and is physically supported on the basis of the central limit theorem, which dictates that within each image cell we have a large number of polarimetric scattering elements, with no one element being a dominant scatterer.

The linear feature vector used during the classification procedure is defined from a new scheme for parameterising polarimetric scattering problems, which has application in the quantitative analysis of polarimetric SAR data. The method relies on an eigenvalue analysis of the coherency matrix and employs a 3-level Bernoulli statistical model to generate estimates of the average target scattering matrix parameters from the data. This alternative statistical model sets out with the assumption that there is always a dominant 'average' scattering mechanism in each cell and then undertakes the task of finding the parameters of this average component.

The scattering entropy / anisotropy, and their combinations, are key parameters in determining the randomness in this model and are seen as fundamental parameters in assessing the importance of polarimetry in remote sensing problems.

Using single-pass data, the « Topography Derivation Procedure », developped by the Naval Research Laboratory [1], can independently produce sets of azimuthal slope profiles spaced throughout the range direction. We show that the $\underline{\alpha}$ parameter can improve the derivation of the Terrain slopes in the range direction, and so, can be used to further improve the accuracy of a Digital Elevation Model.

We show applications of the « H / A / $\underline{\alpha}$ » Polarimetric Decomposition Theorem to some important classical random media scattering problems and apply it to POLSAR data.

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Investigating the Electromagnetic Rationale of Radar Classification Capability

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Classifying among different land categories is a fundamental objective of remote sensing research based on both optical and microwave sensors. Several works indicate that SAR systems have a quite good classification capability, which improves when the complexity in frequency and polarization increases or when multitemporal data are available. The first objective may be reached by airborne SAR's and several works indicate that multifrequency, multipolarization systems achieve valid results even with single flights. The second objective may be reached by satellite systems; the advantages of multitemporality are particularly evident in agricultural vegetation, since radar signatures may be collected at various plant stages and under various situations of soil moisture. In order to fully exploit the performances of both airborne and satelliteborne radars, it is useful to investigate how the different plant geometries affect the radar response and how these effects are dependent on frequency and polarization.

The present work is aimed at giving electromagnetic explanations to the differences in radar signatures due to the different plant geometries, which is the basis of classification. This investigation is useful to establish reliable and efficient criteria of classes selection and to identify the most suitable radar configurations. To this aim, ground truth data collected during several experimental campaigns (from 1986 to 1994) are considered; for several crop types, typical ranges of values are identified for those variables, like stem and leaf dimensions, which have a significant effect on the radar response. The electromagnetic model developed at Tor Vergata University is used to estimate the effects of plant geometrical parameters on the radar signatures, and to investigate how those effects depend on frequency and polarization.

Finally, the experimental data collected over two European sites by the polarimetric multifrequency AIRSAR are considered and a simple classification algorithm is applied at a per-field average level. In spite of the simplicity of the algorithm, the results give useful information, since they confirm the validity of a classes selection based on electromagnetic considerations, allow to estimate the dependence of classification accuracy on frequency and polarization (for various vegetation types) and investigate the advantages obtainable by using backscatter coefficient ratios, instead of absolute values. An estimate is also made of the classification accuracy improvements obtainable when the data of two passages (one in winter, the other in summer) are available, with a radar configuration (L and C band, HH, VV and HV polarization) which should be available in a quite near future.

Knowledge-Based Classification of Agricultural Crops Using SIR-C Polarimetric Data

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A large amount of effort has been invested in understanding, and interpreting, the observed scattering behaviour of electromagnetic waves from different terrain cover types in terms of the underlying physical scattering mechanisms. Especially for polarimetric radar this has led to the identification of the polarimetric characteristics (or signatures) for a number of classes of scattering problems, thus opening the possibility of recognising and classifying land-cover types on a physical and semi-physical basis.

This paper synthesises the results obtained for several agricultural test sites imaged during the two SIR-C/X-SAR missions in April and October of 1994. It will be shown that a number of land-use categories possess distinctive signatures which can be used in knowledge based classification schemes. In many cases the underlying scattering mechanisms leading to the observed signatures can be identified using modelling results. For instance maize fields often exhibit non-zero phase differences between HH and VV polarised signals characteristics of a double-bounce scattering mechanism. The degree of depolarisation is also shown to be useful in discriminating between bare soil fields and those containing various levels of biomass and degrees of plant structure. In some cases however the observed signatures are difficult to explain in terms of interaction mechanisms.

At the same time the results obtained imply that any knowledge-based classification scheme must take into account the underlying statistical models for polarimetric quantities. These define the uncertainties associated with various polarimetric signature parameters and thus their usefulness in classification algorithms.

Session K08
Friday, July 17, AM 08:40-12:00
Room J
Parabolic Equation Techniques for Wave Propagation

Organiser : M. F. Levy
Chair : M. F. Levy, J. Kuttler

Parabolic approximation of acoustic fields in an ocean over a poroelastic seabed

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The problem to be considered in this talk is the determination of the pressure field arising from a sound source situated at some depth in an ocean. In shallow oceans the interaction of sound waves with the underlying sediment cannot be ignored. Traditionally the layers of the seabed have been modeled as homogeneous solid or fluid elastic slabs, but more recent work has focused on the fact the surficial layers of a seabed are porous.

The Biot sediment model regards the seabed as an elastic frame as with interstitial pore fluid. It depends upon twelve physical parameters among them the porosity and permeability of the sediment, the frame elastic parameters and the parameters such as viscosity that characterize the pore fluid. The resulting system of partial differential equations for the motion of the ocean water and the sediment frame and fluid can be solved analytically when the ocean depth and seabed parameters are constant, but such an approach becomes increasingly unwieldy when more complicated bottom profiles and variable seabed parameters are used. In such cases a numerical procedure for calculation of the acoustic field such as parabolic approximation is more feasible.

Parabolic approximation can be implemented using Pade approximation of the square root operator in the factored ocean-sediment system of equations and a Crank-Nicolson/alternating directions discretization. It is valid only in the far field. In this talk we will present more detail on the implementation of parabolic approximation for a poroelastic sediment, discuss stability problems that may arise, and compare predictions for transmission loss obtained from the analytical solution with those obtained from parabolic approximation with the goal of estimating empirically how close to the source parabolic approximation produces accurate answers.

PE Algorithm for Holographic Object Localization

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One of the possible schemes of subsurface radio vision consists of the radar return signal registration on a finite aperture for 3D holographic reconstruction of the scattering objects. In practice it is possible to construct an array containing hundreds of elementary dipoles measuring the amplitude and phase distribution of the scattered waves over the aperture. Backward field calculation produces a kind of diffraction pattern related to the spatial distribution of discrete scatterers or the object details. In this paper, an algorithm solving this inverse problem, based on the parabolic equation (PE), is analyzed. Using numerical simulation, we study spatial resolution as a function of the aprture size, compared with the wavelength, and the number of elementary receivers.

The computational algorithm implements finite-difference integration of the parabolic equation in a rectangular box leant on the receiving aperture. Outside the aperture, the initial data are considered to be zeros, and a smoothing function is used to avoid discontinuity. The PE adequately describes the scattered waves generated by the objects located near the system axis. The traces of the off-axis scatterers that may be present in the initial data are let to leave the computational domain by using boundary conditions of transparency (TBC) applied on the lateral borders. To the zero order approximation, they are derived from an exact solution of the PE in a half-space adjoining to a lateral facet. More accurate TBC's result from taking into account the influence of the neighboring facets. As a model of an elementary scattered wave, a Gaussian beam with the waist of about the scatterer diameter can be used. To simulate the discrete receiver array, we use a piecewise approximation of the initial data. The instrumental errors are introduced via adding a random component to the amplitude and phase distribution over the aperture.

The Parabolic Equation/Fourier Split-Step Method Applied to Two Canonical Problems

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Our numerical routine TEMPER is a split-step Fourier transform method which solves a parabolic wave equation to model electromagnetic propagation through inhomogeneous atmosphere and over the surface of the earth, which, in addition to various dielectric properties, may have large terrain features [Kuttler and Dockery, Radio Science 26(1991), pp. 381-393], [Dockery and Kuttler, IEEE Trans. AP 44(1996), pp. 1592-1599]. Here we use it on two classical problems with known analytic solutions: an incident plane wave scattering from a perfectly-conducting vertical knife edge and an incident plane wave scattering from a perfectly-conducting sinusoidal surface (Bragg scattering). In both problems the incident field is scattered and diffracted into large angles from the horizontal. The point of the exercise was to test the effectiveness of using the wide-angle propagator in TEMPER as a replacement for the narrow-angle propagator. The knife edge edge has an exact solution given by Fresnel integrals. Using the exact solution, we can can compare the numerical results, particularly in the shadow region behind the knife-edge, where energy is diffracted from the tip. The regular sinusoid scatters the incident plane wave into a series of plane waves at angles and amplitudes determined from the Bragg grating law. As expected, the wide-angle version significantly outperforms the narrow-angle one for both of these problems and exhibits remarkable precision when compared with the exact solutions. The sinusoidal results considerably improve on those previously reported in [Kuttler and Huffaker, J. Acoust. Soc. Am., 94(1993), pp. 2451-2453].

Modeling Refractive Effects on Infrared (IR) Transmission Paths Using the Parabolic Equation

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It is well understood that electromagnetic radiation in the communications and radar frequency ranges is drastically affected by atmospheric refraction along the propagation path, particularly when ducting conditions are present. What is often overlooked is the effect refraction may have at electro-optical (EO) frequencies. Aerosol extinction and molecular absorption have always been considered to be the dominant mechanisms by which the transmission of electro-optical radiation is reduced, with aerosol extinction being the predominant reduction factor. In the past, propagation paths for infrared transmission have been somewhat short and relatively far from the surface; therefore, effects from atmospheric refraction along the path could be neglected as a useful first order approximation. In most cases, this first order assumption has worked well. However, due to a convergence of interest in optical paths very close to (within several meters of) the ocean surface in response to the sea skimming missile threat, recent measurements have indicated that refractive effects on these paths can no longer be ignored (Zeisse, *et. al.*, *SPIE Proceedings*, July 1997, pp. 109-122).

Current research on the effects of refraction on IR transmission are based on ray tracing and/or ray optics methods (Forand, *et. al.*, *SPIE Proceedings*, July 1997, pp. 123-134). There are inherent limitations to these techniques, primarily in regions of caustics, for which the ray method breaks down. The split-step parabolic equation (PE) algorithm does not involve ray tracing, and it is not burdened with these limitations. However, there are other problems associated with the PE algorithm in its application to EO frequencies.

A ray optics and PE model have been developed for EO applications in order to analyze infrared transmission measurements taken in November 1996. Both pros and cons of each technique will be discussed, along with prediction vs. measurement results.

Validation of Models for Rough Surface Ducting Cases

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Surface ducts over the sea can result in greatly enhanced signal levels near the sea surface for over-the-horizon paths at sufficiently high radio frequencies. These enhanced signal levels however can be reduced by a wind-roughened sea surface. There are several radio propagation models in use or proposed that account for rough surface effects in a ducting environment, but experimental validation of these models is sparse at best. It is the purpose of this paper to describe an effort to validate one such model using existing propagation data from previous experiments.

The specific propagation model discussed here is the multi-layer waveguide model known as MLAYER, developed by the Naval Electronics Laboratory Center (NELC), a predecessor of the Space and Naval Warfare Systems Center, San Diego (SSC SD). Since MLAYER is a normal mode model, it explicitly contains the modal eigen angles which can be directly related to grazing angles at the sea surface. This model uses a rough surface reflection coefficient reduction factor developed by Miller & Brown (Miller, *et al.*, *IEE Proceedings*, Vol. 131, Pt. H, No. 2, April 1984) that is based on the standard deviation of the sea surface elevation and grazing angle. The Miller-Brown model has been validated by experimental data for paths within the horizon, but not for over-the-horizon ducting environments. Validation of MLAYER for rough surface ducting cases is considered an important step in validating rough surface capabilities of parabolic equation or other propagation models, since MLAYER results could then be used as a validated benchmark for horizontally homogeneous conditions to compare with the other models.

The experimental results come from previous 37 GHz propagation experiments carried out by NELC in the Aegean Sea and in the southern California off-shore area. Results may also be included from an experiment planned for the Wallops Island, Virginia area for spring 1998.

Tropospheric Refractivity Estimation Using Radar Clutter from the Sea Surface

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The vertical and horizontal refractivity profile in coastal regions determines, to a large extent, the performance of shipboard radar and communications systems. If the atmospheric conditions, particularly water-vapor spatial distribution, were known, numerical propagation models could be used for such purposes as predicting detection ranges, correcting altitude estimates, and estimating surface backscatter strength. However, direct measurement of atmospheric conditions is difficult and expensive.

In this talk, an algorithm for estimating refractivity from clutter (RFC) is developed wherein the radar itself is used as a remote sensing device. The complex radar time series for each pulse repetition interval is modeled by a range-dependent two-way propagation loss factor corrupted by a complex Gaussian distributed multiplicative noise representing backscatter from the sea surface and an additive receiver noise component. A maximum likelihood estimate of the refractivity parameters which determine the propagation loss is then derived. Simulation results assuming realistic refractivity profiles are presented which suggest that surface-based duct parameters, such as duct height, can be determined from clutter return measurements given sufficient clutter-to-noise ratio (CNR).

Remote Sensing of Evaporation and Surface Ducts

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Introduction

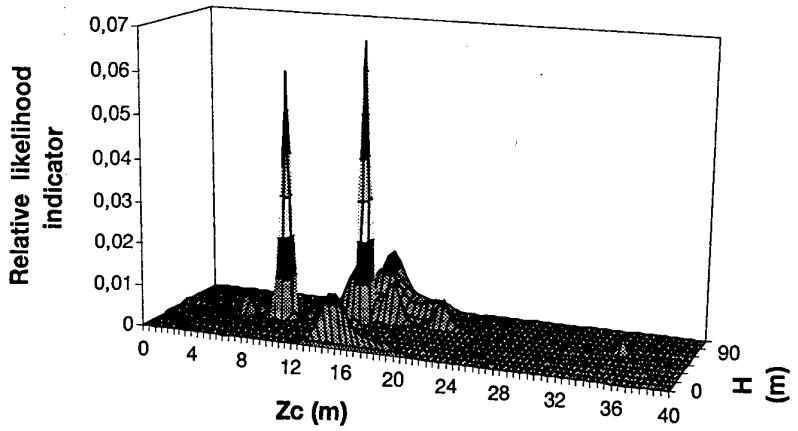
The propagation of cm and mm waves within the Marine Boundary Layer (MBL) is strongly affected by the presence of evaporation ducts. Elevated trapping layers leading to surface ducts may also exists along the propagation path and seriously influence the performances of systems operating at cm wavelengths (SHF band). Evaporation duct heights can be computed using meteorological bulk models, such as PIRAM [1]. Nevertheless, the occurrence and characteristics of surface ducts need radiosonde measurements to be estimated.

The inversion technique

The inversion technique consists of determining both the evaporation duct heights (Z_C) and the elevated trapping layer heights (H) by the means of propagation path loss data [2]. We used experimental results at four frequencies in the SHF band, all concerning low elevation and over the horizon links, collected during two NATO trials : LORIENT 89 (about 60 days of complete data) and TOULON 90 (about 100 days of complete data). For a large set of realistic values of Z_C and H, we computed the predicted path loss values by running a parabolic equation program. These predicted values are compared to the experimental 10 minutes averaged data and, applying a relative likelihood algorithm, we obtained the "best" values for the pairs (Z_C, H), assuming a fixed value of ΔM = -20 M-units, ΔM being the refractivity change within the elevated trapping layer.

Preliminary results and conclusions

In some cases, especially for the TOULON campaign during atmospheric stable conditions but not solely, the inversion method leads to ambiguous results : several different pairs (Z_C, H) may explain the observed values (see figure below).



Example of inversion ambiguous results (LORIENT 89 , 1st of Oct. at 12h20 GMT)
The more likely pairs are (Z_C = 15 m ; H = 70 m) and (Z_C = 9 m ; H = 60 m)

As the evaporation duct heights computed by the PIRAM model are generally found to be very close to the ones deduced from the inversion method, we hope to improve our first results by using the inversion method to compute the pairs (H, ΔM) instead of (Z_C, H).

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Marching Methods for Electromagnetic Scattering Calculations

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This presentation addresses the problem of the scattered field computation of three-dimensional perfectly conducting objects. The size of the object ranges from a few wavelengths to tens or hundreds of wavelengths. The classical full-wave methods (FDTD, method of moments, etc.) are numerically very expensive for such a problem, since all points of the computational domain (or object surface) have to be treated simultaneously.

Marching techniques seem more promising. An example is the parabolic equation method, where 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 with the corresponding boundary conditions on the object surface and absorbing condition on the outer boundaries. The recently developed vector parabolic equation technique [1] provides an efficient framework for bistatic RCS calculations. The method is very accurate for smooth objects and specially for forward scatter. RCS results for perfectly conducting spheres, the NASA almond, ogive and more general shape objects will be presented.

The parabolic equation technique essentially assumes that the currents on the object surface originate from two sources: the incident field and the contribution from the part we have passed as we go along the object. We can reformulate the parabolic equation approach (where we march the field) in terms of currents on the object surface. We call this method current marching technique (CMT). In this case we have to update the current on a contour which is the interception of the object and the marching plane. After the first pass the method gives remarkably good approximation to the surface current. Then backward - forward iterations (like in [2]) can be used to obtain the exact solution. Initial results will be presented.

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Applications of a Parabolic Equation Scattering Technique

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A technique based on the parabolic equation method has recently been developed and applied to scattering from objects in free space [Levy and Zaporozhets, "Target scattering calculations with the parabolic equation method," J. Acoust. Soc. Am. (in press)]. It is based on using a three-dimensional parabolic equation to propagate the scattered field through a region containing the object and enforcing non-homogeneous boundary conditions on the surface of the object. This approach is suitable for more complicated problems, such as scattering from an object embedded in a non-homogeneous background medium and scattering from multiple objects.

Two main modifications are required when the background medium is not free space. Firstly the incident field in the absence of the scattering object must be known in order to modify the boundary conditions on the scatterer appropriately. Secondly information on the background medium must be incorporated into the parabolic equation when solving for the scattered field. We apply these ideas to the case of an object near a boundary or interface. A good leading term approximation is obtained with a single run using the scattering direction of interest as the paraxial direction. Multiple scattering between the object and the interface is obtained by iteration. Next the method is extended to handle multiple scatterers by including the boundary conditions for each scatterer. Possible applications of this approach include be scattering from bubble clouds, a submarine near the ocean surface or bottom, and schools of fish.

Session L10
Friday, July 17, AM 08:40-09:40
Room R01
CEM

Chairs : J. Wiart, A. Zeddam

Correlation of Measurements on Different Sites Using the GPOF Method

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A better understanding of fields radiated by radio equipment and electronic appliances has become a very important issue due to their soaring number and the need to guarantee a high quality of service. Hence a higher uniformity of standards of measurements. Specific standards have been formulated for measurements in anechoic chambers, semi anechoic chambers, and Open Area Test Sites, due to the different nature of electromagnetic (EM) propagation in these sites. It is therefore of primary interest to be able to correlate measured results in these different sites notwithstanding the influence of factors such as imperfect reflecting ground, non ideal absorbing materials or parasitic signals.

The purpose of this work is to put forward a new method for systematic retrieval of results obtained in an anechoic chamber from results measured in a semi anechoic chamber. The strategy employed is to identify the different propagating components, viz., the direct and the reflected wave components using the Generalised Pencil of Function method (GPOF) [1].

We consider two antennas facing each other in a semi anechoic chamber, in transmission and reception mode, and measure the transmission parameters $S_{21}^{semi}(f)$ of the system on the frequency range of interest using a Network Analyser. $S_{21}^{semi}(f)$ includes both the contribution of the direct component and that reflected on the ground. Next we separate $S_{21}^{semi}(f)$ to its propagating components using the GPOF method: $S_{21}(f)=\sum_{i=1}^{M} c_i\, e^{\gamma_i f}$.

A simple scheme based on the identification of the different components of $S_{21}^{semi}(f)$ is proposed to fully reconstruct $S_{21}^{recon}(f)$ of an ideal anechoic chamber. We proceed and add absorbers on the floor thus transforming the semi anechoic chamber into an anechoic chamber, and measure the parameters $S_{21}^{perf}(f)$. Comparison between the reconstructed signal $S_{21}^{recon}(f)$ and $S_{21}^{perf}(f)$ is used for validating the efficiency of the proposed method.

In the presentation several examples of signal reconstitution from measured data will be described in detail including log-periodic antennas in frequency range 400 to 1,000 MHz, and broadband Vivaldi antennas in the frequency range of 1 to 11 GHz for which we claim that the difference between the signal measured in an anechoic chamber and the corresponding reconstructed signal $S_{21}^{recon}(f)$ remains inferior to 2 dB in the worst case on the whole frequency range.

This method is independent of the frequency bandwidth and its requirements in terms of frequency sampling step remain low which makes it very attractive compared to other techniques based on time domain analysis.

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Modified Six Port TEM Cell for Generating Standard Electromagnetic Fields

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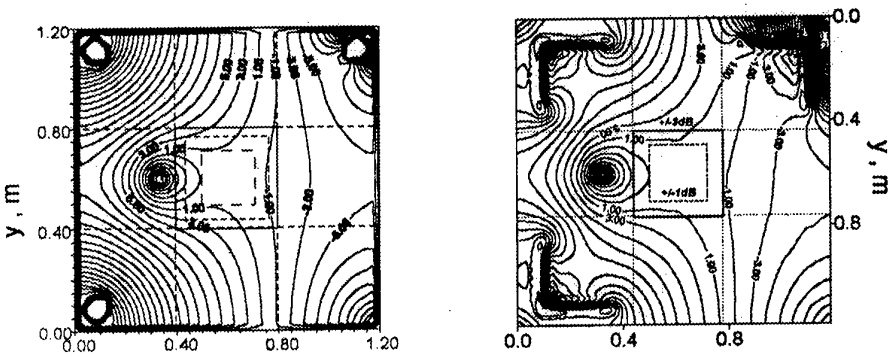
Introduction : Six port (6P-) TEM cell can provide the standard EM fields with higher field uniformity and larger test area than asymmetric TEM cell, GTEM cell, WTEM cell and TTEM cell can, and more easily change the polarization vertically or horizontally. But the operating frequency of that is limited to the cutt-off frequency of first order mode.
Modified six port (M6P-) TEM cell mixed with GTEM cell structure can overcome this limitation, so extend the available bandwith to several Ghz and enlarge the test area with high field uniformity. This cell has the tapered structure with three septa.

Result : M6P-TEM cell is analyzed by the FDTD method. The source field for simulation is modeled using quasi-static theory by moment method. As a result of simulation, we have obtained better uniform TEM field distribution in the test area to the frequency of 1.2 Ghz than those of 6P-TEM cell. Frequency is considered to the range of 1.2 Ghz because of the limitation of memory. Characteristic impedance is matched to 50 [Ω].



a) 6P-TEM cell b) M6P-TEM cell

<Fig.1 Uniformity of the electric field inside the cross section>

As shown in Fig. 1, the field uniformity of the 6P-TEM cell is about 92% in the uniform area (~0.4 × 0.4m), but that of the proposed cell is increased to 100% in the uniform area (~0.325 × 0.325m). The 3dB and 1dB areas of 6P-TEM cell are ~0.325 × 0.325m, ~0.22 × 0.22m respectively, and those of the M6P-TEM cell are ~0.372 × 0.372m, ~0.237 × 0.237m respectively.
Therefore, we can see that the proposed cell has larger test area and better firld uniformity than the conventional 6P-TEM cell does. The result for vertical polarization is the same as for the horizontal one because of the diagonal symmetric structure.

Conclusion : In this paper, we analyzed the modified 6P-TEM cell using the FDTD. The proposed cell is a 6P-TEM cell mixed with GTEM cell structure, and the advantages of the cell are extended available bandwith, the high field uniformity and the maximized test area.

Anti-Shielding Effect of a Cylindrical Grid of Metal Wires

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We analyze the shielding performance of a cylindrical grid of perfectly conducting metal rods or thin wires (a cage) assuming the plane electromagnetic wave of E-polarization (the electric field parallel to the rods) is incident normally to the grid axis.

We formulate the relevant 2D problem in terms of the angular mode coefficients S_{mn} for the fields scattered by different rods. Using the Neumann's addition theorem, we reduce the problem to a set of algebraic equations in coefficients S_{mn} and solve it numerically.

The electric field inside the cage is computed for different values of the cage radius c, of the wire radius a, of the number of wires M, and of the incident wave direction v_0. Also, the field at the cage axis, E(0), as well as the average field inside the cage, <E>, are computed as functions of c.

The field in the cage shows a resonant behavior as a function of the radius c, with the field amplitude increasing at the resonances as compared to the incident field. The resonances occur when the values of c are approximately the roots of the Bessel's functions of the first kind resembling the resonances in the closed perfectly conducting cylinder. The resonant frequencies are, however, of less magnitude as compared to the closed cylinder, so that the more 'open' is the grid (the greater the slots d between the adjacent wires), the less are the resonant frequencies.

Between the resonances and at the low frequencies the grids reveal considerable shielding properties, with the shielding performance increasing when the number of wires increased. However, at the resonances, the field in the cage increases essentially, especially when the number of wires is large and the slots are small. For example, for M=32 wires of the radius a=0.01 lambda (lambdais the free-space wavelength) at the first resonant value of the cage radius c=0.380 lambda (the slots d=0.055 lambda), the field in the center is 19 dB greater than the incident field E_0.

The results demonstrate that one has to be careful about using the grid or mesh cages as shielding structures, especially in unknown high-frequency environment, since some unexpected high-frequency radiation may cause a damage of the devices due to the field enhancement shown above.

Session L11
Friday, July 17, AM 09:40-12:00
Room R01
Educational Electromagnetics

Organizers : M. Helier, W. Tabbara
Chairs : M. Helier, W. Tabbara

Web-based Lessons, Changing the Face of Electromagnetics Education

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Because electromagnetic fields obey a set of four coupled partial differential equations, Maxwell's equations, and the analysis is typically mathematically abstract, high-powered computers have long been necessary tools for numerical analysis and visualization in electromagnetic research and education. This need for computational power has traditionally limited the dissemination of both research and instruction materials. Recent advances in Web-based technology, such as the JAVA programming language (Sun Microsystems, Inc.) and QuickTime Multi-media technology (Apple Computer, Inc.), coupled with low-cost high-speed desktop computers has dramatically increased the availability and accessibility of information on electromagnetics. Electronic lessons and software can readily be distributed to students. We will discuss how this technology can be used to not only enhance traditional course content, but also how it changes the content and structure of the course. Topics that were once too difficult to attempt can be effectively explored by students. Students, who once studied in isolation, can participate in electronically linked groups. The focus will be on how to increase discussion, exploration, and participation. Examples can be accessed at http://maxwell.ucdavis.edu/~electro/ .

Electromagnetics on the WEB

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Electromagnetics on the WEB is a part of a larger project concerning an individual learning system, using hypermedia documents for undergraduates of scientific universities. This project is sponsored by the french Ministry of Education and must be seen as a national large scale development of former local experiments made in the frame of the Self-Learning University Centre Network (called RUCA, in french).

The system is designed to be usable in distance learning scenarios, so that it will function efficiently as a replacement for conventional lectures, for tutorial support, for lecture demonstrations and for self-study in the libraries and the resources centres.
For instance, the students remaining on the same level of courses for two years, or having some lack of knowledges in some domains, or again having to prepare a new orientation will have the possibility to use these documents.

This project ,which is essentially developed for the first year of scientific education students, includes four general topics : Mathematics, Physics, Chemistry and Biology. The products will be conceived in the same way in order to obtain an homogeneous presentation.

The participants (teachers of ten french universities) have selected a group of common contents corresponding in a first step to the basic knowledges of the first year scientific level. The first phase of the project consists in 14 units. Particularly, interferences, electrostatics and magnetostatics are 3 among the 7 units of the "Physics" topics.

Each unit contains an hypermedia document including :

- text (theoretical data with hypertext links)
- interactive exercises
- animation
- simulation and modelization
- video documents showing real experiments
- references
- self evaluation tests

With the authorization of the authors, the texts can be easily modified by the teachers for a personalization of the resources.

Every unit is atomized into micro-objectives corresponding to only one notion. Such a structure allows an easy use of the resources in a lot of particular contexts. It will be possible to use the products issued of this project in many ways chosen by different teachers or by the users. As a final goal, it will be possible to tie an individual learning plan to the results of the self-evaluation tests.

This kind of educational product has been successfully tested in the frame of the RUCA universities and with the public of self-learning students.

A World Wide Web Teaching and Learning Environment with Computer Algebra Systems Applied to Educational Courses of Electromagnetics. Examples and Hyperlinks

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The Computer Algebra Systems (CAS) are one of the tools of Computer Aided Mathematics Calculus. This kind of calculus is well considered highly by mathematicians, engineers, and students because it includes the possibility of immediate numerical experimentation. A wide range of various applications exist today : physics, engineering, mathematics, medicine, economics, commerce, etc. The CAS avoid encumbering the course with long calculations, and the students can concentrate on more important topics, for example the physics of the studied phenomena [1-2]. It is a great opportunity to explore new issues that were previously difficult to tackle in the classroom. The CAS are coming in teaching, particularly with the new hypermedia techniques as the World Wide Web, HTML and, Java languages [3-7].

The implementation of a hypermedia based educational system for the mathematical sciences, the electromagnetics, for example, with the help of the CAS allows to generate and randomize exercises and to check the students answers. The web facilities and videoconferencing software allow to enhance interaction between the teacher and the distance learners. For example, in mathematics, the structure of the courses consists of text, mathematical dictionary or database of definitions, exercises, examples and computer aided interactive exercises.

In this paper, we present many experiences in teaching and learning domains in the world. We give many informations on the organizations, the universities, and so on which have developed hypermedia services for the education, particularly in electromagnetics. We add Web addresses of various sites, specialized serials and electronic magazines.

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[7] D. Small, Computer Algebra Systems in Education, Department of Mathematical Science, U.S. Military Acadamy, West Point, New York, 1996.

Some Web addresses

SAME Symbolic & Algebraic Manipulation in Education	*listserv@frulm11.bitnet*
CAINPB-Education	*http://www-math.uni-paderborn.de/user/cube/CAIN/EDU/school.html*
Computer Algebra Network and Education	*http://www.can.nl/Education/index.html*
Computer Algebra in Mathematics Education	*http://www.can.nl/SAC_Newletter/CAME.html*
The Teaching and Learning Technology Support Network	*http://www.tltp.ac.uk/tltsn/index.html*
Calculus & Mathematica Distance Education Program	*http://www-cm.math.uiuc.edu/dep*
Mathematica In Education and Research	*http://telospub.com/journal/MIER/index.html*

The World Wide Web and The Information Retrieval : Methodologies and Examples in Electromagnetics

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The aim of this communication is to present research methodologies for engineers and researchers. Numerous examples are taken from the field of electromagnetics, such as the diffraction of objects, the modeling of antennas, etc. The efficiency of certain available research tools, with the public isn't really familiar, will be demonstrated as well as the type of research carried out (patents, conference articles, Ph.D. thesis, etc.).

The rapid development of telecommunication is leading to a considerable quantity of information sources available on the Internet with 15 millions sites, 110 millions users and billions of indexed words. Sites are characterized by their mobility and versality. Whether at the levels of research organisms or industries, the fields of technological, competitive, commercial or as well environmental surveillance, find new ways of investigation.

Searching for and finding relevant information is still a difficult task. Thus, research must become integrated into a structured research plan using other on-line sources.

Anybody using the network for the first time is soon astounded as the quantity of information available (whether they have to pay for it or not). Thousands of answers exist, although we know that, in general, the average user doesn't look beyond the first ten or twenty. Basically, the problem is knowing where to locate interesting and reliable sources and how to eliminate excess results. Research tools exist. Indexes and directories (All-In-One Search Page, EuroLink, Four11, WhoWhere, World Wide Yellow Pages, Yahoo!, etc.) offer good services with few irrelevant results. Search engines (Alta Vista, Excite, HotBot, InfoSeek, Lycos etc.) based on the automatic indexation of resources provide a vast quantity of results. However, they are always superfluous and sometimes irrelevant. Metaengines (Internet Sleuth, MetaCrawler, SaavySearch, etc.) attempt to combine the advantages of both these research tools. They must be used professionally and it is necessary to make use of their advanced research module (Advanced Research of Alta Vista and its Live Topics, Lycos Pro, etc.). Intelligent agents or assistants are being devised (AfterDark, My Yahoo!, Point Cast Network, Search 97, etc.). They carry out a linguistic analysis of the results. Following a research equation established before-hand, the agent selects the documents by interpreting them, then eliminates doubles and classes them in order of relevance. This criteria is in relation with the density, the proximity and the place of the elements of the request in the title, the abstract or the text, for example. The consultation of library catalogues, journal contents, summaries of articles etc. is often free but users are increasingly being obliged to pay in order to obtain the whole text. Furthermore, the most important publishing houses (Academic Press, Blackwell Science, Elsevier, John Wiley, Springer Verlag, etc.) have put their latest products at the public's disposal and offer such services. They are even FirstSearch products from OCLC (Online Computer Library Center) and Uncover from Knight-Ridder.Researchers who are expert in very specialized fields will progressively turn to reading electronic magazines on Internet, which will reduce their expenses.

Electrical Engineering Teaching : New Tools, New Approach

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The traditional teaching of electrical engineering is facing the problem of using only abstract notions like charges, fields or induced currents in materials. Furthermore, theses notions are manipulated using even more abstract vectorial or differential operators. This is one of the main reasons why most students in the domain of electricity do not have a deep understanding of the basic principles, even if they are able to solve standard problems.

We have now the possibility to use the fantastic power of the today's desktop computers to find new and more intuitive representations of the studied phenomena. This offers to the students easy-to-use and highly interactive software packages and lead them to understand intuitively and deeply the most basic laws and notions.

The main problem, when designing such an application, is to give an instant response to any modification of parameters : any user interaction has to cause a modification of the displayed results in a sufficiently short delay. Therefore, a judicious solving method has to be chosen depending on :

- the quantities that the teacher wants to show
- the range of input parameters
- the time needed to solve the problem

The CEGELY is involved in the field of the Computer Aided Education (C.A.E) for Electrical Engineering since a few years. Table 1 shows how the solving method has been chosen depending on the nature of the application. In some cases, the choice of an analytical solving is obvious. On the other hand, the finite element method (F.E.M) is more adapted, especially when local quantities have to be represented in awhole space (such as the distribution of flux density or eddy current density), and when no simple analytical equation may be solved.

Problem	Dimension	Objectives	Chosen method	Why ?
flux density in airgrap of rotating machine : mField	1D	how to obtain a rotating field ? What does it mean ?		
guided micro-waves : mWave	2D	understand propagation modes in rectangular/circular waveguides	analytical	very fast
flux density, energy in a magnetic circuit with air-gap : *Contact*	2D	understand leakage flux, saturation. Where is the electromagnetic energy ?	finite elment method	local quantities and non-linear problem
flux density in a DC motor : *Motcc*	2D	see *Contact* what is the influence of the compensation windings ?	finite elment method	local quantities and non-linear problem
eddy-current in a single sheet : *Coufou*	2D	understand eddy-currents distri-bution for different types of material, for different frequencies	finite elment method	local quantities
impedance of a coil above coated sheet (thickness measurement) : *PlanImp*	2D	what is the evolution of the impedance versus the materials properties and the frequency ?	analytical	global quantity with a wide range of variations of the parameters

Table 1 : which method for which problem ?

Electromagnetica
A Mathematica based electromagnetic course

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The use of software tools in engineering education is getting more attention from academics as a possible mean of increasing the receptiveness of students to abstract subjects or ideas in a curriculum. Although the main effort was directed toward the development of simulation tools, a number of computer-based courses, with a more or less broad scope, have been devised. More recently, web-based learning added a new possibility to motivate students in their struggle with abstract topics in engineering courses. Electromagnetics, often seen as a by-product of mathematics, is a first choice candidate for these new means of learning.

We have started a project, named Electromagnetica, by mean of which we aim at developing a set of "electromagnetic notebooks" each one dealing with a particular topic in the field of electromagnetic waves, such as polarization, dipole radiation, reflection... This package is based on a library built using the programming language of Mathematica. Each notebook is a short course presenting the main features of the topic it is concerned with, as well as examples and when necessary animations. Exercises will also be available.

Mathematica, as a computer algebra system, allows the user to build up computations from Maxwell's equations to get acquainted with the fundamental concepts. As a numerical and graphic tool, Mathematica will help the user to visualize the electromagnetic fields encountered in practical cases.

This presentation concerns the first notebook which deals with some fundamental concepts in electromagnetics such as Huygens principle, Green's function, elementary sources... These concepts are better handled by means of generalized functions (distributions) which will be introduced through well known applications such as propagation over a transmission line, radiation of electric and magnetic dipoles...

Session M08
Friday, July 17, AM 08:40-11:00
Room R03
Dielectric Measurements on Low Loss Crystals
Workshop on Complex Media and Measurement Techniques

Organiser : J. Baker-Jarvis
Chairs : J. Baker-Jarvis , J. Krupka

Dielectric Characterization of Low-Loss Materials : a Comparison of Techniques

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The goal of this paper is to present measurements on a large number of commonly used low-loss materials using a number of techniques. We also compare and contrast measurements on the same materials using different measurement fixtures. Measurements on low-loss materials using closed and open cavity resonators, surface-wave modes, and dielectric resonator methods are presented.
Not all materials were measured at the same frequency or on all fixtures.

The materials tested were ceramics, plastics, glasses, and single crystals. Intercomparison of techniques is very useful for reference material characterization. Results indicate that consistent measurement results can be obtained with a number of well-characterized fixtures. Typical uncertainties associated with each method are addressed. Measurements were also performed on materials used in previous intercomparisons.

It was found that surface-wave mode techniques are the most accurate for loss measurements. However, in these types of techniques, only the very surface of the specimen is sampled. TE_0 dielectric resonators yield very good accuracy for low- loss materials. TE_0 cavity resonators are useful for slightly higher-loss materials and have slightly less accuracy than Dielectric resonators. Most resonant techniques have the disadvantage of being limited to the gigahertz region. The reentrant cavity is one of the few accurate resonant techniques that can measure in the 100-500 MHz region.

Dielectric Properties of Extremely Low Loss Single Crystal Dielectrics at Cryogenic Temperatures

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The whispering gallery mode technique is one of the most accurate methods for evaluation of complex permittivity of both isotropic and uniaxially anisotropic low-loss materials. We have employed this technique to measure dielectric properties of several single crystal dielectric materials at cryogenic temperatures, including sapphire, TAG, rutile and SrLaA104. A mode-matching technique was used to find a rigorous relationship between the complex permittivity, the resonant frequency, and the dimensions of a resonant structure. The frequency range over which dielectric properties are evaluated for sapphire is 14-23 GHz, that for YAG 15-25 GHz, for rutile 3-7 GHz, and for SrLaA104 8-16 GHz. The total uncertainty in permittivity is smaller than 0.05% and is limited principally by the uncertainty in sample dimensions. the uncertainty inloss tangent principally depends on the uncertainty in measurements of the unloaded quality factor. Measurement results include permittivities, dielectric loss tangents and thermal coefficients of permittivities in the temperature range 4-300 K for uniaxially anisotropic and isotropic material. In some of the materials under study, losses at temperatures close to 4 K were extremely low ($\tan\delta$ on the order of 10^{-9} -10^{-8}). By using appropriate dimensions of the enclosing metal shield and by performing measurements on whispering gallery modes having sufficiently high azimuthal mode numbers, it is possible to make all losses in the resonant system negligible except for dielectric losses in the specimens under test. This makes it possible to perform dielectric loss measurements with extremely high resolution.

Cryogenic Dielectric Resonators and their Applications

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Dielectric resonators have the potential to provide high Q-values at cryogenic temperatures. Basically, this is due to the intrinsic contribution of microwave losses in ionic crystals arising from the interaction with the lattice vibrations, which decreases strongly with falling temperature. However, the losses at low temperatures are limited by defects, with tanδ as low as several 10^{-10} for sapphire and 10^{-8} for rutile. Crystals with more than two species of atoms per unit cell generally exhibit higher losses with temperature dependences dominated by defect-dipole relaxation rather than intrinsic losses. However, tanδ values of several 10^{-6} are achievable, e.g. for $LaAlO_3$ with ε_r=24. Polycrystalline microwave ceramics provide only moderate reduction in tanδ upon cooling, the low-temperature values are typically not below 10^{-5}. The advantage of many ceramics is a small temperature coefficient of the permittivity, providing sufficient frequency stability for dielectric resonator devices.

However, one would like to take advantage of the high Qs of single crystals at low temperatures, either by providing sufficient temperature stability and/or by using composite single crystals with small net temperature coefficient. As an example, we have developed a dual-mode filter based on two degenerate modes in a $LaAlO_3$ hemisphere with Qs of 10^5, resulting in insertion loss values as low as -0.02 dB up to levels of several tens of watts of microwave power. The filter housing consists partially of a high-temperature superconducting film, resulting in a negligible loss contribution from the filter housing. This provides high Q and low mode density, as required for the use of such filters in satellite communication.

A second example is high-Q resonators with zero temperature coefficient of the resonance frequency at a certain temperature. Such resonators are envisaged to be used for low-phase noise and frequency stable oscillators, even secondary frequency standards are considered. So far, we have investigated whispering gallery modes in composite sapphire-rutile resonators and achieved turning points (e.g. 1/f df/dT =0) from 40 to 80K with Qs in excess of 10^6 at 17 GHz. Similar to the filters, such resonators can be operated on low-power cryocoolers. Therefore, we believe that cryogenic dielectric resonator devices can be used in a broad range of military and commercial applications.

High Q Liquid Helium Cooled Dielectric Resonators and Measurement Applications

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Microwave resonators based on single crystal dielectrics with very low losses are able to provide very high Q values. Such resonators form the basis of a number of precision measurement applications which will be discussed in this talk.

The best known potential application of liquid helium cooled, superconductor shielded sapphire single crystal dielectric resonators is as flywheel frequency standards for use with the next generation of atomic frequency standards such as the caesium fountain. The requirements on the sapphire dielectric for this application are extreme mechanical and thermal stability and steps must also be taken to reduce the frequency dependence of the effective permittivity if unattainable levels of temperature control are to be avoided. We discuss various techniques of temperature compensation, including paramagnetic impurity doping and composite dielectrics, and report experimental data on a 4.2K sapphire resonator with excellent long term frequency stability.

High Q dielectric resonators also have a number of other promising measurement applications, including precision microwave measurements, spatially resolved surface impedance monitoring and temperature measurement and these applications will be summarised. A basic physics measurement involving an attempt to perform a laboratory search for the time-variation of the fine structure constant will also be described.

Measurements of Doped and Composite Low Loss Single Crystal Dielectric Resonators for Secondary Frequency Standards

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New electromagnetic techniques to compensate the frequency-temperature dependence of low-loss monocrystal sapphire microwave resonators have been investigated. Dielectric compensation was achieved by constructing a composite resonator from mono-crystalline sapphire and rutile (TiO_2). Compensation was achieved in different modes from 8-17 GHz from 50 to 150 K, with Q-values varying from 5 million to 300 thousand.

Another technique under investigated was the doping of Ti^{3+} and Ti^{4+} ions into the sapphire lattice. Two 2.5 cm diameter crystal with 0.03 to 0.1% doping of Ti^{3+} and Ti^{4+} ions were measured from Crystal Systems, as well as a 1 cm diameter crystal with 0.1% doping from Poland. The Crystal Systems Ti^{3+} sample was measured to have compensation points in the range 30-75 K with Q values of the order of a few million, while the Polish crystal had compensation points in the range 45-50 K with Q values of a few hundred thousand. The crystal systems Ti^{4+} doped crystal was measured to have compensation points at lower temperatures below 30 K with Q-factors in the excess of 10 million. From our experiments, the compensation effects seem to be due to the paramagnetic effects of the Ti^{3+} ions inside the sapphire lattice.

These new compensation techniques for low loss crystals give the possibility of building frequency stable fly-wheel oscillators with a frequency instability of 10^{-14} without the necessity of cooling to liquid helium temperatures.

Overview of Theoretical Background for Dielectric Measurements on Low-Loss Crystals

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The present understanding of the theory explaining the loss mechanisms in crystals as a function of frequency and temperature is overviewed.

Braginsky discovered anomalous low values of dielectric loss in single-crystal alumina in 1977. In this study dielectric resonators were used to measure the loss tangent. Since then there has been a large body of research performed using dielectric resonators which supports these results. The whispering-gallery mode technique is the most accurate way of measuring loss tangent of low-loss materials. All of these researchers claim that the loss tangent follows roughly a T^4 dependence at low temperatures.

It has been found that crystals with a center of symmetry, generally, have lower loss than ones with noncentrosymmetry. Temperature dependence also depends on the crystal symmetry. For example, sapphire, a symmetric molecule, has much lower loss than noncentrosymmetric ferroelectric crystals such as strontium barium titanate. In nonpolar materials, such as many crystals, the significant dielectric loss mechanism is due to interaction of phonons with the applied electric field. Phonons are quasiparticles of energy quanta, which result from lattice vibrations. In the absence of an applied electric field the lattice vibrates almost totally harmonically. Electric field interaction modifies the harmonic elastic constant and thereby introduces an anharmonic term. The anharmonic interaction allows phonon-phonon interaction and thereby introduces loss.

Most of the loss in crystals is due to interaction of the photon quanta of the electric field with the lattice vibration phonons. There are many types of phonon losses. The three quantum loss corresponds to transitions between states of the different branches. Four-quantum loss corresponds to transitions that take place between states of different branches. Quasi-Debye losses correspond to transitions which take place between the same branch which has a finite width. In centro-symmetric crystals three and four-quantum processes are dominant. In noncentro-symmetric crystals the three-quantum and quasi-Debye processes dominate.

Theory backs up the temperature dependence observed in measurements on many low-loss crystals. Gurevich [Gurevich, 1991, Adv. Phys., **40**, 719] has shown from phonon theory that the loss tangent in crystals should satisfy a temperature dependence of the form of T^4. The loss tangent for cubic and rhombohedric symmetries for temperatures far below the Debye temperature T_D where ε is permittivity, ρ is density, v is speed of sound, and T_D=1047K is the Debye temperature.

$$\tan\delta = \frac{\omega^2 (kT)^4}{\varepsilon \rho v^5 \hbar (kT_D)^2}$$

Session A11
Friday, July 17, PM 13:40-15:20
Room 300
Diffraction and Electromagnetic Waves
Chairs : W. Tabbara

Diffraction of a Flat H-Polarized Wave on a Slot Under Magnetic-Dielectric Cover

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A new method of account of a slot on an ideally conducting plane of final sizes under thin magnetic-dielectric film (a model problem of account of a slot-hole aerial under a cover) on the basis of Pocklington integral equation with an exact singulare nucleus is offered. Dependences of the dispersion-diagram depending on the size, kind of an impedance load, width of a slot and width of a screen are received.

The impedance dipole is studied in many works of home and foreign investigators. At the same time the problem of finding effective methods for solving integral equation is actual.

The authors suggest the following scheme of solving this problem :

1. As a development of the ideas of the work [1] we prove that the integral equation of the impedance dipole is Fredholm's equation of the second kind in some Gilbert space.
2. Then we prove that the equation has a unique generalized solution.
3. Making use of the existence and uniqueness of the solution we carry out a qualitative analysis, that is studying the asymptotic behaviour of the solvation distraction coefficients by the basic set.
4. Using the qualitative analysis we build the numeral analytical method of the solution of the integral equation and investigate the effectiveness of this method. For a simpler process we consider the axis-symmetrical excitation of the cylindrical dipole when the primary electric field $E_z^0(z,\varphi) = E_z^0(z)$ doesn't depend on the angular coordinate φ accordingly.

The surface current $j_z(z)$ will depend only on the length of the dipole.

In order to make the description more laconic we'll prove the basic assertions for a simple case when the surface impedance is a constant value since the aim of this work is the description of a new idea. It lies in the fact that all the information about the surface current can extracted from the equation itself. In book [2] the characteristics of the surface current are studied in terms of solving an auxiliary problem of diffraction on the impedance half-plane.

Alongside with all these we'll be hoting the ways the results of this work can be generalized for the variable surface impedance Z.

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Electromagnetic Returns from Dielectric Media with Imbeddes Wires

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The reflected return of electromagnetic waves from dielectric or metallic surfaces can be analytically espressed by the Fresnel coefficients which also describe the refrected wave that penetrates into the medium. These expressions are valid for infinite homogeneous, isotropic media with surfaces smooth compared to the wavelenght ; they also describe the polarization of the reflcted and refracted waves. If the polarization (electric) vector of the incident wave is perpendicular to the plane of incidence, this will also be the case for the reflected and refracted wave, and similarly, for the incident polarization vector parallel to the plane of incidence, so that no coupling of linear polarizations occurs.

One may attempt to modify the polarization of waves reflected by the surface of a dielectric (which may be lossy), by imbedding in it short, thin wires (needles) that are randomly distributed and oriented. Our previous study [H. Uberall et al., J. Appl. Phys. 73, 3441 (1993)] has considered such media for the cade of inclusions small compared to the wavelength ; for that case, one was able to use « effective medium theory » which represents the material as one homogneous medium with effective properties. In the present case, we choose to leave open the possibility of wires that are not necessarly short compared to the wavelength, so that effective medium theory will no longer be used, but individual wire scattering has to be consedered. The corresponding scattering cross section of one wire (assumed perfectly conducting) is known, and the scattered wave combines coherently with the surface-reflected wave, both being generated by the same incident wave. The effects of the randomly distributed diferent wires can, however, be added together incoherently. We find that the polarization of the scattered wave is of purely parallel type and thus adds to the parallel-typeFresnel reflection, while the perpendicular-type Fresnel reflection is not affected by the wire scattering. The total parallel-type response (reflected and scattered) is superposed with different phases necessitating a characterization of polarizations by the (real) components of the Stokes vector, of which only the first two are non-vanishing since only linear polarizations are being considered here. Numerical calculations show the influence of scattering from the imbedded wires on the polarization of the total (reflected and scattered) returns.

Diffraction by Screens with Two and Three Dimensional Hollows

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We consider the problems of wave diffraction by planar, perfectly conducting screens with arbitrary finite two-dimensional (cylindrical) and three-dimensional (spatial) hollows and dielectric inclusions situated over the screen. The analysis is reduced to the study of boundary value problems in domains with noncompact boundaries; therefore, the majority of well-developed method cannot be applied. We use generalized formulations with the partial Sveshnikov--Reichardt radiation conditions at infinity and reduce the problems to operator equations that are obtained in terms of variational identities and considered, in the Sobolev spaces, in bounded domains. The operators are nonselfadjoint, Fredholm, and finite-meromorphic with respect to the complex spectral parameter ω; the unique solvability is proved in the upper half-plane of ω. General properties of complex eigenfrequencies are established.

For the numerical solution of the obtained Fredholm operator equations of the second kind, we construct a substantiated scheme of the Galerkin method, where the basis functions are determined by solving boundary value problems in {\it {bounded}} domains and the expansion coefficients are calculated from the matching conditions that have the form of projectional relationships. The uniqueness of approximate Galerkin solutions is proved, as well as convergence of the method.

Efficiency of the method is demonstrated for perturbed planar screens with irregularities and inclusions of specific shapes (cylindrical semicircular grooves with circular dielectric pivots, hemispherical hollows, etc.), although, in principle, the method is universal and can be applied (by means of appropriate parametrization) to arbitrary irregularities of the boundary. The results are obtained in the form of colored maps of the near and far fields and frequency dependences of basic integral characteristics of scattered fields.

A General Theory of Diffraction by Perfectly Conducting Capacitive Grids

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In previous papers presented at PIERS, we have described the theory of diffraction by capacitive grids composed of a square array of perfectly conducting, circular cylinders, and illuminated by a normally incident plane wave. In this paper, we extend the previous treatment to accommodate off-axis incidence and concentrate on the derivation of the modes in the grid region—a generalisation which, in the case of the transverse magnetic polarisation, is not straightforward. Indeed, a careful analysis has revealed that our previous inability to identify an acoustic band (ie. a mode whose frequency approaches zero with wavenumber, and which determines the long wavelength transmission of energy) for this polarisation can be overcome by replacing the strict Dirichlet condition satisfied by the mode potential (from which the transverse components of the fields are derived) by one that imposes "source neutrality" combined with constancy of the potential around the cylinder boundary. We show also that given this formulation, the resulting combination of TE and TM modes for the long wavelength limit is precisely that corresponding to the case of normal incidence, as required.

We outline the solution of the diffraction problem by a mode-matching technique, and proceed to demonstrate the validity of the formulation through a variety of tests. We present numerical results indicating that the formulation satisfies various completeness relations, Babinet's Principle and common phase properties. We outline the derivation of the common phase property in the long wavelength limit (for which there is only a single propagating order in reflection and transmission), a result that underpins the derivation of equivalent circuit models for thin grids and the homogenisation of grids whose thickness is not small in terms of equivalent thin films.

High Frequency Difraction by an Open Ended Parallel Plate Waveguide Cavity with Impedance Walls

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The scattering of high frequency electromagnetic waves by open ended waveguide cavities is an important topic in diffraction theory from both theoritical and engineering point of wievs . As is well known , this problem serves as a simple model of duct structures such as jet engine intakes of aircraft bodies. Some of the cavity diffraction problems have been analyzed using the waveguide model approach , high frequency ray techniques , and the Wiener-Hopf techniques [1]. In all these investigations the walls of the cavity are assumed to be perfectly conducting and the main objective of this work is to extend the analysis carried out in [1] to the more general case where the walls forming the waveguide cavity are impedance boundries.

By using the "image bissection principle" the original problem is converted into two simpler problems as shown in Fig.1. The expansion of the total field in the waveguide region into a series of normal modes and the use of the Fourier transform technique elsewhere , one obtains a "modified Wiener-Hopf equation" (MWHE) of the second kind for each excitation. The solution of these equations contains a set of infinitely many constants satisfying an infinite system of linear algebraic equation. numerical solution of these system is obtained for various values of the surface impedance and the size of the cavity from which the effects of these parameters on the diffraction phenomenon are studied.

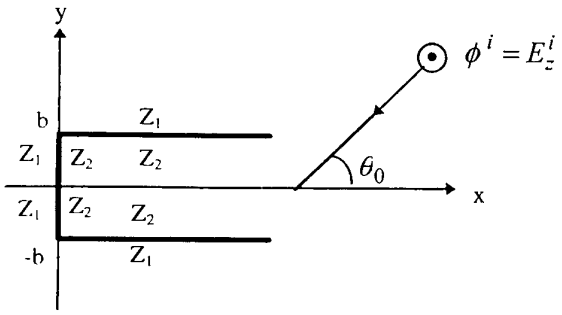

Fig.1a. Magnetic Wall Bissection (Even Excitation)

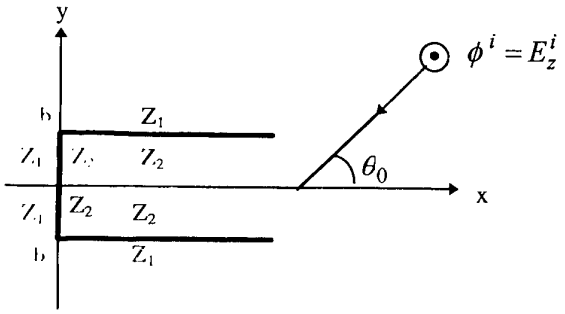

Fig.1b. Electric Wall Bissection (Odd Excitation)

Session A12
Friday, July 17, PM 15:40-16:40
Room 300
Electromagnetic Formulation
Chairs : H. Baudrand

Fractionalization of Kernels for Electromagnetic Intermediate-Zone Fields in Cylindrical and Spherical Geometries

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Inspired and motivated by the concept of fractionalization of differentiation and integration operators, which is the subject of the field of fractional calculus in mathematics, in our previous work we analyzed fractionalization of some other commonly used operators in electromagnetism such as the cross product and curl operators [1-3] which has led us to the fractionalization of the duality principle in electromagnetic theory [1-3]. Our interest in fractionalization of these operators in electromagnetism began with exploring potential roles and physical implications of the mathematical machinery of fractional calculus in electromagnetic theory. In our earlier work, we have applied the concept of fractional calculus in certain electromagnetic problems, and have obtained some promising results illustrating some interesting features of these operators [see the review article 4].

Since fractionalization of these operators effectively addresses the "intermediate behavior" for such operators, we have been motivated to explore the potential roles of such fractionalization in the treatment of problems involving intermediate zones in electromagnetism. For example, in the antenna theory and the aperture problems, usually more attention has been paid to the analysis of the far-zone and the near-zone fields while less attention has been aimed at the intermediate zone. Based on our recent analysis, we have shown that by fractionalizing the proper kernels that relate source fields and the far-zone fields, one can obtain new kernels that would provide information about the intermediate-zone fields. The case of planar geometry for such fractional kernels is being planned to be submitted for presentation in another upcoming symposium [5].

In this talk, we will present our results for fractionalization of kernels for other cases of the cylindrical and spherical geometries and we will show how these fractional kernels relate the source fields with the intermediate-zone fields.

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Comparison of Eddy Currents Computation by a h Formulation and by a e Formulation

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When one has eddy currents to compute, two formulations seem to be particularly interesting, based on two different unknown, quantities : the magnetic field h or the electric field e. In both cases, the implentation combine a finite element method (FEM) in the conductors and a boundary integral method (BIM) to describe the contribution of the exterior domain (the air). Which one to choose is not obvious.

In the h formulation, the h field in the air is written as : $h = h^S + \text{grad}\ \varphi$. H^s is the source field. The normal reaction field on the boundary is related to the scalar potential by $\frac{\partial \varphi}{\partial n} = R_\varphi \varphi$.

The operator R_φ is classically computed by introducting, as an intermediate, a layer of single charges on the boundary. The induced current in the conductor is j=curl h. In the e formulation, the e field in the air is written as : $e = e^S - \frac{\partial a^r}{\partial t}$ and we need the relation between the tangential reaction magnetic field and the vector potential : (curl $a^r)_t$=$R_a a^r$. The operator R_a is computed by introducing, as an intermediate, superficial currents on the boundary. The induced current is j= σ e.

Using these two formulations, we computed the eddy currents in a sphere embedded in an alternative homogeneous magnetic field. The results were compared with the analytical solutions. The CPU times were also compared. The conductor was meshed with tetrahedra. Edge variables were used, with the exception of nodal variables in the h formulation for φ on the boundary. The operator $R\varphi$ was computed by means of rotating currents k around each node of the boundary ; they verified curl k=0. The detailed comparisons will be given in the whole paper.

An Alternate Characteristic Equation for a Cylindrical Dielectric Waveguide

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Propagation modes in a cylindrical waveguide with three regions are defined by a characteristic equation that relates the propagation constant to the indices of the two regions and the radius of their interface. It is derived from two equations that are implied by the boundary conditions for the electric and magnetic fields at the interface :

$$k_1 a \frac{J'_m(k_1 a)}{J_m(k_1 a)} = -\frac{|m|}{K_2^{\,2}}\left(\frac{1}{P}\frac{\kappa_2 \omega^2}{c^2} - P\omega_z^{\,2}\right)$$

$$K_2 a \frac{K'_m(K_2 a)}{K_m(K_2 a)} = \frac{|m|}{k_1^{\,2}}\left(\frac{1}{P}\frac{\kappa_2 \omega^2}{c^2} - P\omega_z^{\,2}\right)$$

where a is the radius of the interface, κ is a relative dielectric constant, ω_z is the propagation constant, and P is the polarization parameter whose value defines a mode as HE or EH. The characteristic equation is derived by combining the equations by the elimination of P.

An alternate defining equation may be derived by eliminating the radius of the interface instead of the polarization parameter. The resulting equation relates the propagation constant to the indices of each region. It can be expressed as an equality of two functions, each of which is a function of the propagation constant and the index of a single region :

$$f_1\left(\frac{\omega_z}{\omega n_1}\right) = f_2\left(\frac{\omega_z}{\omega n_2}\right)$$

where n_1 and n_2 are indices of refraction. The form of the functions f_1 and f_2 permit a straightforward computation of ω_z and P in terms of the dielectric constants of each region. From these quantities, the radius of the interface can be calculated easily.

The technique is applied to the computation of $\omega_z / n\omega$ for different values of the polarization parameter and different interface radii for low order propagation modes. The specification of dielectric waveguides in therms of these parameters is described and compared with the more usual description of ka as a function of V. The relationship between the possibility of solutions to the characteristic equation and the forms of f_1 and f_2 is discussed.

Session B09
Friday, July 17, PM 13:40-16:40
Room G/H
Scattering II
Chairs : M. Saillard

Angular Variation of Diffuse Scatter from Discrete Inhomogeneities in Terrestrial and Icy Surfaces : Results from 3-D FDTD Simulations

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A significant fraction of diffuse radar scatter from geophysical surfaces is due to discrete, wavelength-scale heterogeneities *e.g.*, rocks, fractures, pits, and other geological inclusions buried within or resting on the surface. Characterizing the scattering behavior of such heterogeneities poses significant theoretical challenges due to i) the irregular shape of most discrete scattering objects, and ii) their proximity to the boundary separating free space from the surface. The finite-difference time-domain (FDTD) technique provides a convenient numerical means to overcome these challenges. In our Cartesian-grid FDTD implementation we approximate the surface as a homogeneous, lossless, dielectric half-space. The composite field which "drives" the scattering consists of an incident plane wave and the reflected and transmitted plane waves associated with the planar surface (in the absence of a scatterer). The radar cross section calculation proceeds as in standard free-space FDTD implementations; however, the Green's functions associated with current sources above and below the surface differ considerably from the free-space Green's function.

Using polarization synthesis to simulate arbitrary transmitter/receiver polarization states, we have analyzed the angular variation of backscatter from three-dimensional wavelength-scale objects of various shapes, ranging from ideal spheres to laser-scanned digitizations of terrestrial rocks realistic models whose scattering properties have not been characterized previously. Both the shape of the scatterer and its location relative to the surface have a strong effect on the angular scattering dependence. For a circularly polarized incident wave, for example, the same-sense circular response from buried spherical scatterers has a null at normal incidence. Both the same-sense and opposite-sense circular responses from rock-like buried objects, however, vary approximately as a cosine power law (which peaks at normal incidence) in accordance with many diffuse scattering models. Backcattering from rock-like objects resting on the surface exhibits a more complex angular variation, which has a local maximum at high incidence angles (70°–75°) and is sometimes bimodal. Our results suggest that, on rocky planets such as Mars, buried rocks are a large contributor to diffuse scatter, despite the much stronger individual radar return from surface rocks.

We have also begun to investigate and will present preliminary FDTD results for some of the scattering models which have been proposed to explain the "bizarre" radar echoes signatures of ice from the Galilean satellites of Jupiter, the poles of Mars and Mercury, and the Greenland ice sheet. Retro-refraction of waves guided by smooth radial permittivity variations and radar glory from buried craters are two such models. These have been analyzed previously in the geometrical or quasi-wave optics limit; FDTD simulations may establish their effectiveness as wavelength-scale scattering centers. In addition, bistatic FDTD cross section calculations important for constraining the width of any scattering enhancement can be obtained at very little additional computational cost over the monostatic cross section.

Scattering Models for the Rice Crop Growth Monitoring

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Backscattering Models are developed for the project " SAR Rice Crop Monitoring in the Southern China" of China 863 hi-tech program. The goal of the modeling work is to investigate the scattering mechanism of the wave-rice crop interaction and to finally retrieve rice crop growth parameters and crop productivity.

Two models are used for our project: a two-layer model based on radiative transfer theory and Monto-Carlo simulation which incorporates the coherent scattering part. In two cases the underlying ground surface is assumed to be covered by water, is thus a specular plane. Two main constituents of the rice crop are considered : leaves are modeled as elliptical dielectric discs and stems as circular dielectric cylinders. Scattering amplitude for them are calculated from classic analytical expressions. Input parameters for the models include rice crop parameters such as leaf and stem size, orientation angles, water content, and wave parameters such as frequency, polarization, inicent angle, etc. .

Simulation computation is made to test the model sensitivity with input parameters. Comparisons are also made with results from available publications. As for the real world computation, detailed field measurement on rice parameters are made simultaneously with SAR data acquisition at 24-days interval by Radarsat. The resulted calibrated SAR data are used to check the validity of the model.

From the modeling results, it is believed that the height of the rice crop as a critical parameter to identify the growth stage has hight relation coefficents with the backcattering coefficients. In-depth analysis of the results and evaluation of the potential of model-based applications for rice monitoring purpose is still undergoing.

3-D Scene Modeling and Remote Sensing Applications

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A combined computer graphics/radiosity 3-D scene model and its primary applications in remote sensing of vegetation are presented in this paper. The model accommodates three-dimensional radiative exchange in both visible and near-infrared regions within architecturally realistic vegetation canopies. The basic components of the model, such as L-system rendering of 3-D objects, the radiosity equation and its solution, view factor calculations, and 3-D image display of the objects, are described, with emphasis on L-system representation of 3-D objects and computer graphics based methods for view factor calculations. Through this 3-D model, scene statistical characteristics (both physical and structural), which are essential for terrestrial ecological studies, are directly rendered. Primary results of current applications in remote sensing are then presented. These include calculation of bidirectional reflectance factor (BRF) for both heterogeneous vegetation canopies and large scale non-flat terrains, computation of areal proportions of important scene radiometric elements--sunlit and shaded components of the scene and their contributions to the scene reflectance under a given sun-view geometry, how Normalized Difference Vegetation Index (NDVI) is correlated with each component for vegetation stands, and a feasibility study, i.e., to explore optimal sampling domain for a best estimation of a particular structural parameter from BRFs. The future steps to extend its application domain into the mid and long-wave infrared, are also briefly discussed.

Angle-Resolved Ellipsometry of Light Scattering for Separating Surface and Bulk Effects

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For an increasing number of applications it becomes necessary to identify the origin of light scattering from optical substrates and thin film multilayers [1]. This problem is rather complex due to the fact that most often surface and bulk scattering exhibit similar behaviours, depending on the choice of parameters that are involved to take account for surface roughnesses and bulk inhomogeneities [2]. We show that the mesurement of the phase difference between two polarization states of the scattered waves may provide a technique to solve this problem [3]. Depending on substrates, coatings and illumination incidence, the angular behaviour of the polarimetric phase difference is strongly dependent on the origin of scattering. A large number of numerical exampmes is presented. In a second step we apply the ellipsometric techniques to light scattering in order to measure the angular variations of the phase term. Numerous data are presented for several multilayer designs, which allows a detailed comparison of theory and experiment. The result clearly shows the presence of a ripple in the phase term, that must be connected to interferences between surface and bulk scattering, and to a partial vertical correlation of defects within multilayers.

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Exact Model for Scattering from Periodic Rough Surfaces

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An exact model is developed for describing the scattering from periodic rough surfaces. In the past, the scattered fields were described by an infinite series of Floquet modes, which for computational purposes, has to be truncated. In this model, a technique is developed for representing the infinite set of non-propagating (evanescent) modes in terms of the finite set of propagating modes. By substituting a finite length series of propagating modes for the non-propagating modes, the scattered fields are described by a finite length series which may be evaluated exactly. The model is then used to calculate the backscatter from ocean-like rough surfaces for a range of incidence angles. Perturbation analysis is used to show the correspondence between this model and existing analytical models such as the slightly rough model and the composite surface model. The model is used along with an analytical form of the ocean surface wave model to calculate the normalized radar cross-section at various wind speeds. The model is also used to derive the polarimetric signature of ocean-like surfaces. A time-dependent ocean surface model is also used to calculate the Doppler signature of the backscattered signal. The model results used to assess the geophysical information content of imaging radars, scatterometers and altimeters.

Scattering from Natural Rough Surfaces Described by the FBM Fractal Model

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The problem of electromagnetic scattering from randomly rough surfaces has been widely studied [1-3], because it is of great interest in the fields of telecommunications and remote sensing. During last decades different approaches to the solution of this problem have been developped, based on different approximations and having different ranges of validity [2-4]. In all these approaches the surface is described by means of a stationary stochastic two-dimensional process, with given probability density function (usually Gaussian) and correlation function (usually Gaussian, exponential or combinations of these).

However, it has been recently shown [5-7] that a new description , based on fractal geometry, seems to be more suitable to the modelling of natural surfaces. In particular, self-affinity of soil surfaces on wide range of scales and the shape of their measured spectra ($S(f) \propto \left(\frac{1}{f}\right)^{\beta}$) lead to model these surfaces by means of a fractional Brownian motion (fBm) two-dimensional process [5]. Results of some pioneering studies on the use of fractal surface models for the problem of electromagnetic wave scattering have been recently reported (see e.g. [7]). Within this framework, we explore in this paper use of the fBm model with Kirchhoff approximation approach, and we evaluate in a closed form the mean square value of the scattered field.

The fBm process is non-stationary, but its increments over a fixed horizontal distance τ are stationary Gaussian processes with zero mean and variance to $T^{(2-2H)}\tau^{2H}$, where H is related to the fractal dimension D by D=3-H, and T is the topothesy, i.e., the distance τ over which chords joining points on the surface have an rms slope equal to unity. Stationarity of increments allows us to analytically evaluate (by means of the Kirchhoff approximation) the mean square value of the field scattered along an arbitrary direction by a surface illuminated by a plane wave. This allows to elucidate the dependence of the scattered field on the surface fractal dimension and its topothesy.

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Non Destructive Testing of Heterogeneous Structures with a Step Frequency Radar

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Ground penetrating radar have shown increasing potential in diagnostic of soils or concrete, but the realisation of such a system and the interpretation of data produced by this technique require a clear understanding of the physical electromagnetic processes that appear between media and waves. In this paper we study the performance of a step frequency radar as a non destructive technique to evaluate different heterogeneous laboratory size structures and we study some critical points, like material properties, antenna effect and image reconstruction algorithm, to determine its viability to distinguish smallest region of interest.

First, to determine the specifications of the radar system and interpret its response, we need to establish the relationship between the propagation of the waves (velocity and attenuation) and the electromagnetic properties of the media. We study the complex permittivity of the material through different experiments and models. The dispersion of the dielectric permittivity and the electric conductivity is measured with an open ended coaxe placed on the surface of a sample, or by the knowledge of the reflection and transmission coefficients through the material and two antenna in free space. Those data are compared with estimations via dispersive models, and used for numerical simulations and image reconstruction algorithms.

Second, as the system antenna is used in near field, we study the effect of a stratified media in the vicinity of an electric dipole, to evaluate the perturbations on its radar response. Analytical solutions, numerical simulations (via finite difference method) and experiments are used to study the influence of high conductive media or media with dispersive properties.

Thirdly we correct the response of the radar system by a reconstruction algorithm, to obtain an image of the induced current in the structure, which allow the distinction of the region of interest. Classical methods of microwave tomography (filtered back propagation or synthetic aperture time domain focusing) are compared to solve the inverse problem and give a sufficient resolution on the order of centimetre. Images with data obtained by numerical simulations and experiment are compared.

Finally, tests on more complex heterogeneous structures with different system configuration (frequency, polarisation) show the effect of polarisation in complex media, and demonstrate the viability and limits of wide band radar system for non destructive testing of such structures.

Numerical Analysis of Radar Scattering from Turbulent Flows and Rough Bodies of Rotation

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1. Introduction

In this work we consider scattering of electromagnetic waves on the nonstationary turbulent flows of liquids, gases, plasma and rough cone and paraboloid. Three types of indicatrix over-radiation elements of rough surface: isotropic, Lambert and quasi-mirror are analysed. The indicatrix of over-radiation of rough surface of quasi-mirror type is asymmetrical. The main part of energy scattering signal is concentrated in the vicinity of the direction of mirror reflection of wave from surface. The analitic expressions and numerical results for angular and frequency spectrums scattering signal were received for three types of indicatrix over-radiaion inhomogeneous.

2. Method of calculation.

We consider the propagation of wave through axially symmetrical flow with inhomogeneous profiles velocity and concentration of turbulences. It is suggested that length of wave is smaller then size of flow and scattering occurs incoherent manner on statistic independent turbulences. The method of stochastic modeling is applied for solve of task (V.G. Spitsyn, Journ. of Communicat. Technol. and Electronics. 6, 730-734, 1996).

3. The results of calculations and its comparison with experimental data

Comparison the results of calculation with experimental data is conducted for case scattering ultrasound on turbulent flow of water (A.N. Barchatov, V.G. Gavrilenko, and A.I. Martianov, Acoustic Journal, 32-35, 25, 1979). Carrying out of comparison calculation and experimental curves of frequency spectrum permits to make the conclusion about that in experiment the maximum of profile velocity turbulences is disposed on the axis flow and the maximum of profile concentration - on the surface of flow.

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 surface is dynamic rough and the turbulences are moved along her formative. The calculation of angle and frequency spectrums of scattering signal is conducted. In results of calculations it is determined that with growth of order equation describing the scattering surface focusing of the signal to axis of flow takes place.

The comparison of the form of experimental frequency spectrum, received in the result of calculations and experimental data 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, 1568-1573, 8, 1970.) is spent. Carrying out of comparison calculation and experimental curves of frequency spectrum permits to make the conclusion that such spectrum of the reflected signal appears as the result of multiple scattering of electromagnetic waves on the inside surface of turbulent plasma paraboloid of rotation.

4. Conclusion.

We consider the multiple scattering of electromagnetic waves on the strong fluctuation dielectric penetration the flow of plasma. The analytic expressions for radar cross section and frequency spectrum scattering signal on the external surface of turbulent flow of plasma has been found. The comparison of results of accounts with experimental data on ultrasound and electromagnetic sounding of a flows of water and plasma has been spent. It has been shown their satisfactory conformity and has allowed to receive the information about parameters of a flows.

Session C09
Friday, July 17, PM 13:40-18:00
Room I
The Methods of Lines for Computational Electromagnetics

Organisers : R. Pregla, W. Pasher
Chairs : R. Pregla, W. Pasher

New Developments in the Method of Lines

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The Method of Lines (MoL) has been proved to be a very suitable procedure for realistic modeling of wave propagation in waveguides for microwave, millimeter and optical wave frequencies. Numerical stable tools for the analysis of complex structures were developed. Even radiation and various types of antennas have been analyzed. In the past time new ideas for using this method were introduced. The accuracy of the algorithms has been improved and new fields for using algorithms based on the MoL were opened.

In this contribution some of the most important steps introduced into the MoL in the last time will be summarized and its usage for the analysis of complex structures will be demonstrated. Furthermore, new developments will be described and verified by numerical examples.

One of the most important concept introduced into the MoL is the impedance/admittance transfer concept [1] [2]. This concept allows the analysis of circuits consisting of concatenations of a high number of waveguide sections with numerically stable algorithms. By introducing Floquet's theorem Bragg grating structures with even more than ten thousand periods can be analyzed in short time [3]. This concept was furthermore extended to structures with layers (sections) of anisotropic and even gyrotropic material [4].

Another new and important concept is that of using crossed lines. This concept is now also combined with the impedance/admittance transfer concept mentioned before and in this way a powerful tool for the analysis of waveguide bends and crossings (junctions) is obtained [5]. It will also be shown how this concept can be used for eigenmode analysis in waveguides with complex cross sections and with precise resolution of the modal fields and high accuracy of the propagation constant [6],[7].

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Electromagnetic Modelling of Microwave Structures and Filter Design with the Method of Lines

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This paper is concerned with the application of the Method of Lines (MOL) to the full - wave analysis of three - dimensional structures and especially microwave planar filters. For resonators, a free oscillation analysis leads to field distribution and resonant frequencies by solving an indirect eigenvalue problem. For the calculation of scattering parameters (forced oscillation analysis) inhomogeneous boundary conditions are introduced in the access planes :

$$\psi_e\big|_{z=0} = \psi_{e0} \qquad \left.\frac{\partial \psi_h}{\partial z}\right|_{z=0} = -j\beta\ \psi_{h0}$$

Ψ_{eo} , Ψ_{ho} and the propagation constant β are solutions of a two - dimensional analysis of the transmission line in the access. For better efficiency and flexibility a nonequidistant discretization is systematically used.

In a first approach, the frequency responses of various structures are computed with this method. Results are compared with measurements and/or data from other simulators, mainly a Finite Element (FEM) software developed at IRCOM. On two microstrip gap discontinuities from 1 to 10 GHz, a good agreement is observed. On the transmission coefficient of a $\lambda/2$ resonator around 9,3 GHz and of a square patch around 4 GHz, the frequency shift ,between numerical results, is less than 50 MHz. And the 3 dB bandwidths are comparable. The MOL is well suited for modelling this type of structures. A limited number of lines is needed and it provides a good compromise between accuracy and numerical performance. It also allows a good description of measurement conditions.

In a second approach, we propose to apply the MOL to the rigorous design of microwave planar filters. We present results for a two - pole Tchebychev filter at 5,4 GHz and four - pole elliptic function filters at 2,4 and 5,4 GHz using square open - loop resonators. First of all, the design method requires an accurate characterization of mutual couplings between the loops. A free oscillation analysis with the MOL is performed to model the coupling coefficients that are extracted from the resonant frequencies of odd and even modes. We apply a forced oscillation analysis to model the input and output coupling : The external quality factor is deduced from the frequency response of the phase of the reflection coefficient (S11) of a single resonator excited by a tapped feed line. Such a procedure provides the physical dimensions of the devices. To verify the design, a global analysis still using the MOL is performed. Scattering parameters are very close to these of the localized elements circuits satisfying specifications of the filters (center frequency , bandwidth). First experimental results confirm this good agreement. So it appears that the MOL, quite accurate in its predictions, is a relevant tool for the design of microwave planar filters.

The MoL - a Competitive Analysis Tool for Filters ?

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Due to the half-analytical nature of the method of lines (MoL), the method is known for its highly accurate results. It is easy to understand, straightforward to implement and it has been very successfully applied to a lot of different two- and three-dimensional structures in the field of microwaves and integrated optics. Nevertheless the method is not as popular and widely used as it could be expected. Why? One reason could be the limitation to layered or cascaded geometries, another the tedious search for zeros in the analysis of eigenvalue problems, which might enforce manual interaction of the user. One main drawback is certainly the calculation speed and the required memory for complex structures. Unfortunately the fact that we discretize in one direction less than necessary and calculate analytically in the remaining direction does not necessarily result in lower calculation time and storage, because we always have to deal with full matrices.

In this presentation it will be investigated, to what extend these prejudices are true. For that reason a certain class of structures are analyzed, for which the MoL should be highly suitable, namely microstrip and rectangular waveguide filters. These structures exhibit a strictly cascaded geometry with edges along the coordinate planes. Since the model leads to a deterministic problem, no search for zeros is necessary as for eigenvalue problems [1]. The calculation time will be reduced by some special means, for example a structure dependent discretization.

The results obtained by the MoL will then compared comprehensively with results obtained by other numerical methods with regard to accuracy, calculation time and storage requirement. The aim of this presentation is a statement, how far the MoL is competitive to other methods and where its advantages or disadvantages are for this class of structures.

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Scattering of a Finite Elliptic Cylinderby a Combination of MoL and Generalized Multipole Technique

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A combination of the Method of Lines (MoL) and the Generalized Multipole Technique (GMT) is introduced for the analysis of round scattering objects with planar end surfaces. The GMT [1] is employed for the treatment of round surfaces whereas the planar and angular parts are investigated by the MoL. This ensures a good modeling since each part of the scatterer is analyzed by the best-suited method. In this contribution the combination is achieved by a separation of variables and not by the domain partitioning previously employed [2].

The GMT is a very favórable method for the investigation of scattering at round objects like spheres. Cylinders of arbitrary (e.g. elliptic) cross-section or even more general "potato-shaped" objects, can be easily modeled. However, the GMT is not applicable to bodies containing sharp edges. On the other hand, the MoL is particularly appropriate for the analysis of layered geometries and objects with planar surfaces. Top and bottom surfaces of the finite cylinders are conveniently modeled. The electromagnetic field is very accurate even near the metallic or dielectric edges. Absorbing boundary conditions are employed to take radiation into account. In case of finite cylinders the wave equation is discretized and numerically solved in the axial direction only. A transformation to principal axes converts the original 3D problem into a set of decoupled partial differential equations in the transverse plane.

The resulting 2D wave equations are solved analytically in free space and inside the scatterer by the GMT. For this purpose a superposition of several suitably placed multipoles is used. The electromagnetic field of the incident plane wave and the scattered field are matched numerically at the curved interfaces of the scatterers. A generalized point matching technique is employed which uses a higher number of matching points than unknowns and thus yields an overdetermined system of equations. This means increases the precision of the results considerably.

Using this hybrid approach a finite elliptic dielectric cylinder illuminated by a plane wave is investigated. The distribution of the scattered electromagnetic field is presented.

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Shielding of Two Broadside Coupled Single Microstrip Lines by a Non-ideal Metallic Layer

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From one side the coupling between two strip- or microstrip lines is a useful effect which has been extensively studied. It has led to couplers using sophisticated techniques, e.g., couplers with inhomogeneous coupling. On the other side the coupling between two lines can be a very disturbing effect which should be greatly reduced. In the multilayer techniques the shielding of two line planes is often realized by a ground plane inserted between them. The mechanism is well known. However, the requirements for size and weight reduction leads continually to smaller spacing between the ground and the line plane and to thinner metallization. Hence, a detailed information on shielding is necessary. Although there are several papers dealing with a lossy metallic ground plane, including the more recent ones [1-3], nevertheless, their subject is not the shielding effect associated with the lossy metallic ground plane.

In this contribution two identical microstrip lines arranged like the lines in a broadside coupler but separated by a non-ideal metallic layer are investigated. Concerning the coupling as an disturbing effect this arrangement is somewhat like a worst case. The metallic layer is assumed to be homogeneous and described by its specific electrical conductivity. The analysis is done by the Method of Lines [4-6] which is well suited for the given problem. The metallic layer is introduced into the analysis by its corresponding pure imaginary dielectric constant [7]. The lines themselves are supposed to be lossless and infinitely thin. The symmetry of the structure is taken into advantage, i.e., the behaviour is described by the even- and odd-mode parameters.

The complex propagation constants for both even- and odd-mode are presented for several values of specific electrical conductivity and of layer thickness in the range from 1kHz to 1GHz. These parameters are used to define a coupling coefficient. Its reciprocal value is a measure for the shielding effect. The results demonstrate in which frequency range the shielding is more crucial, and to what degree the electrical conductivity and the thickness of the metallic layer influence the effect of shielding.

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Analysis of A Shielding Structure Using the Method of Lines Coupled with the Mode-Matching Method

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In a packaged (monolithic) microwave circuits, the parasitic fields would be excited by active devices and/or discontinuities in the circuits and propagate in the form of the higher-order modes (spurious modes) of the shielded transmission line. To guard the circuit from the electromagnetic interference (EMI) caused by the spurious modes, suitable approaches should be adopted to choke off the undesirable waveguide modes. In this paper, a simple structure formed by two metal patches symmetrically deposited at the two sides of the center microstrip, as shown in Fig.1, is proposed and analyzed for shielding the higher-order modes in a waveguide-packaged microstrip line circuit. The patches are to be etched on the substrate at the same time as the fabrication of the microstrip line circuit, thus making this shielding design easily realized. The variations of the effective dielectric constants and field distributions for the modes in the packaged microstrip line with side patches, with respective to the patch width (w_p), were first investigated using the method of lines. The results suggested that there exist a range of patch widths at which the field distributions of the higher-order modes are totally different from those of the microstrip line without side patches, which means the patches can mostly reflect the powers of the spurious modes. The scattering characteristics of the patches were then studied using the method of lines coupled with the mode-matching method. In the analysis, the surface integrals of the mode-matching solution are expressed in terms of the transformed field values. Since these fields are discretized only in the x direction while they are analytical in the y direction, small amount of computer memory are required by using this method. It has been found that, by simply choosing appropriate patch sizes, the parasitic higher-order modes can be completely shielded without sacrificing the normal propagation of the dominant mode.

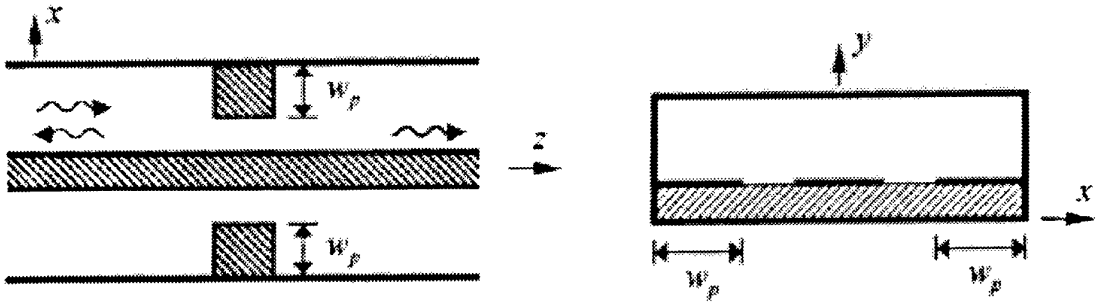

Fig.1 : Top and cross-sectional views of the shielding structure for analysis

Optical Pulse Propagation in Nonlinear Quadratic Materials

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Recently a great interest has been given to the propagation of self-guided beams or spatial solitary waves in quadratic media. Although the existence of solitary waves of second order nonlinearity was already pointed out in the 70s , the renewed interest has prompted accurate analytical and numerical investigations on the nature and properties of these waves, with also emphasis on phenomena potentially useful for all optical processing in particular into the waveguide geometry. Successful experiments in KDP and lithium niobate and the observation of optical steering, have provided further impulse to this field.
In the present paper we consider stationary fields propagation in a planar waveguide with quadratic nonlinearity in the configuration of second-harmonic amplification (Type I interaction (eoo)).
We assume that both fields (fundamental at ω frequency and generated field at 2ω frequency) are present at the waveguide input. We additionally suppose equal shape of the two input beams .

We study the propagation of pulses when they are superimposed at the waveguide input, then we study the interaction process when the two input beams (at the fundamental frequency) are located at different input positions, forming an angle between them.

The nonlinear propagation is studied applying the " Method of Lines" (MOL) ; a comparison between different numerical methods of solutions of the coupled system of equation governing the process is performed.-
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Modeling High-Speed Optoelectronic and Microwave Radiative Components Using the Method of Lines

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This paper discusses the formulation and application of the MoL (Method of Lines) to electromagnetic modeling problems encountered in two areas of recent interest. The first concerns modeling problems in high-speed optoelectronics and the second concerns the modeling of microwave dielectric radiating elements. Recent advances in the formulation of the method will be discussed and new modeling results will be presented.

An important class of structures commonly encountered in high-speed optoelectronics and in integrated optics is that of the inhomogeneous anisotropic waveguide. A simple and elegant formulation of the MoL capable of handling most waveguides fabricated from such materials has recently been developed. The advantages and limitations of our formulation, which is approximate, will be discussed and criteria will be given to help assess whether the method can model with reasonable accuracy a particular waveguide of interest.

High-speed optoelectronic devices often require the use of planar metallic waveguides to apply or detect an electrical signal at microwave frequencies, and optical waveguides for the transmission of the optical signal through the device. In such structures, three electromagnetic modeling problems of interest are solved using our MoL formulation. The first consists in characterizing the microwave guiding structure, the second is the characterization of the optical waveguide, and the third consists in the analysis of the coupled structure formed by the optical and microwave waveguides at optical wavelengths. This later case is of practical interest in modulator and photodetector circuits where the microwave guide runs over a considerable length of optical guide and/or when both are in close proximity. Recent results that describe the effect of metallizations on optical signals will be shown.

Finally, the MoL is applied to two- and three-dimensional structures in which dielectrics may be inhomogeneous and of finite extent, in an unbounded-space environment. Our formulation allows the computation of radiation losses and is extended to multilayered cylindrical structures. Leakage and resonance are modeled and computed for radiating dielectric resonators of various cross-sections; results will be shown for a number of structures having this topology. Experiments have also been carried out to verify the accuracy and usefulness of the MoL for such applications. It is believed that this technique is very useful for modeling certain three-dimensional unbounded structures having a multilayered dielectric cross-section and planar metallizations for which methods that apply a complete spatial discretization (such as finite-element and finite-difference methods) are not efficient.

Efficient Analysis of Planar MMICs Printed on Anisotropic Substrates Using the Method of Lines

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In this research, we present the results of applying the Method of Lines (MoL) to the analysis of common discontinuities found in planar monolithic microwave integrated circuits (MMICs) that are printed on anisotropic substrates. Considering the added complexity to Maxwell's equations due to the material anisotropy, we started the formulation from the matrix form of Maxwell's equations, rather than following the conventional MOL techniques. We applied the generalized differential matrix operators (GDMOs) and derived a pair of coupled differential equations for the electric fields tangential to the metalization, which govern wave propagation in planar anisotropic media. By applying the Kroneker product convention in a matrix form and assuming general solutions for the fields in the anisotropic medium, we derived an impedance Green's function for the planar structure. This Green's function can be directly used in numerical computations to obtain the propagation constants and modal fields of MMIC structures. To accelerate the convergence of the numerical solution to discontinuity problems, we combined our MOL formulation with the transverse resonance technique (TRT) and used an accurate initial guess for the cavity resonance. Finally, we validated our MOL formulation for MMIC structures that are printed on anisotropic materials by analyzing various uniform transmission lines and microstrip step discontinuities.

Rigorous Analysis of Non-Homogeneous Gyrotropic Waveguides by the Method of Lines

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The analysis of gyrotropic devices is generally based on the assumption of idealised homogeneous magnetisation. However, optimum performance will be achieved only by non-homogeneous magnetisation in some applications. Hence, idealised models provide only a rough prediction of the electrical response of real devices. Therefore non-homogeneous magnetisation must be considered to avoid high experimental effort the device design.

In the presented work, the Method of Lines (MoL) is extended to the analysis of non-homogeneous gyrotropic waveguides. The approach is shown to provide a rigorous and systematic solution with arbitrary orientation and size of the magnetisation in the ferrite materials (Fig. 1). The waveguide is partitioned into various layers with different magnetisation and material properties. In contrast to other MoL approaches not second order differential equations (d.e.) but Maxwell's equations are considered directly. They are transformed into a d.e. system with four field components for each layer:

$$\frac{d}{dz}\begin{pmatrix} e_x \\ e_y \\ h_x \\ h_y \end{pmatrix} - A(\gamma_y)\begin{pmatrix} e_x \\ e_y \\ h_x \\ h_y \end{pmatrix} = 0$$

A: matrix with the derivative in the x and y direction
z: is the direction of the lines

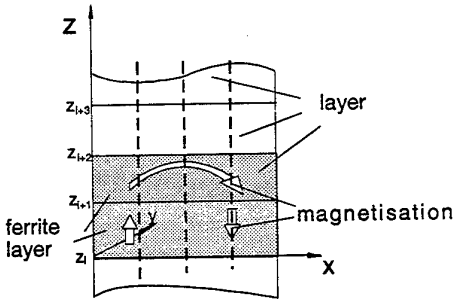

Fig.1 General analysis model with non-homogeneous magnetisation

The first order coupled ordinary differential equations are advantageous for the analysis of gyrotropic structures because they directly yield the different eigenvalues in positive and negative directions. The discretisation lines are perpendicular to the propagation direction y. The field components are discretised in x direction and become vectors $\mathbf{E}_{x,y}, \mathbf{H}_{x,y}$.The magnetisation and the permittivity tensors are discretised as well. First, the differential equation has to be solved for each layer to obtain a transfer matrix for the field components from one side of the layer to the other.

There are two approaches to obtain a solution:

(1) the eigenvalues λ and eigenvectors T of the matrix A are calculated to solve the d.e.

$$(\mathbf{E},\mathbf{H})^t_{i+1} = T e^{-\lambda(z_{i+1}-z_i)} T^{-1} (\mathbf{E},\mathbf{H})^t_i$$

(2) a series expansion of the matrix function $e^{-A(z_{i+1}-z_i)}$

The eigenvalue solution provides high accuracy, but has the disadvantage of time and memory consuming computation. The series expansion needs only low computation time and reduced memory and is optimally suited for thin layers. With the transfer matrices for the field components from one layer to the other an implicit eigenvalue problem (e.g. $\mathbf{Z}_{(\gamma_y)}\mathbf{E}_{x,y} = \mathbf{0}$) can be generated under consideration of the boundary conditions - which finally yields the propagation constants and the eigenvectors.

The advantage of this approach over the classical one is demonstrated by the comparison of computed and measured results of a microstrip line magnetised in different orientations.

New Capabilities of Method of Lines to Characterize Planar Antennas with Finite Substrate

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Most analysis of planar structures are achieved assuming that the substrate and the ground plane are infinite. The investigation of recent development in microwave and millimeter wave integrated circuits and antennas shows that these analyses are not valid when the size of the substrate and (or) the ground plane is finite. To solve the three-dimensional layered structure without discretized the whole volume, one of the efficient approach is based on the resolution of the Sturm-Liouville equation by the method of lines [1-2].

This paper gives an extended approach for microstrip antennas and circuits having finite size substrate. It combines the method of lines with the Green's functions. The formulation includes also a rigorous description of the feeding generator and the matched load termination which are introduced as additional boundary conditions and used to calculate the scattering parameters and the radiating field for multiport antennas and circuits. A special care is taken in order to improve the absorbing boundary conditions by a numerical compensation procedure using a complex dielectric constant.

Using this hybrid approach the influence of the finite size substrate on the propagation characteristics and the scattering matrix parameters is investigated for radiating and non radiating structures. The obtained theoretical results are compared to our measurements and show a good agreement. The improvement provided by the present approach is obvious in the input impedance and the radiating patterns specially when the borders substrate are close to the radiating edges of the microstrip patch.

Several examples will be presented to illustrate the capabilities of the present approach.

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Session D09
Friday, July 17, PM 13:40-15:20
Room 120
Advanced Topics in FDTD

Organiser : B. Jecko
Chairs : B. Jecko, F. Jecko

Matrix Formulation for the Analysis and Design of Synthetic Linear and Nonlinear Materials

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Various types of artificial materials constructed from lattices of electrically small loaded antenna elements that are embedded in some host medium have been considered. Theses artificial molecules consist of electric (linear) and magnetic (loop) dipoles loaded with linear and nonlinear circuits. The equivalent polarization and magnetization fields of these artificial molecules and their defining differential equations have been obtained for a variety of loads.Several material models can be recovered with these artificial molecules. They include the standard Debye and Lorentz materials but also novel choices including the time-derivative Debye, the time-derivattive Lorentz, and the two time-derivative Lorentz models. Various interesting parameter regimes of these passive material models have been studied with FDTD calculations for their use as electromagnetic absorbers. Active material models have also been considered ; they result from the introduction of active circuit elements, such as diodes, transistors, and operation amplifiers, into the circuits which load the elemental antennas. The actual usefulness of the resulting active materials as «smart skins» has also been assessed usinf FDTD calculations. By a «smart skins» we mean a surface that could actively respond to variations in the incident field. As was done with the passive artificial material models, the generalized polarization and magnetization field equations have beeen coupled with Maxwell's equations in a natural way and solved numerically with the FDTD approach.

We will present a brief review of our work on these linear and nonlinear elemental artificial molecules and will introduce a novel matrix differential equation formulation for the analysis of their response. This approach is a state space method that allows one to treat the fields and circuit quantities on an equal footing ina FDTD formulation. It is fully explicit approach. If the load is linear, a simple linear system of update equations can easily be derived from the system of differential equations describing the behavior of the load circuit. If the load contains one or more nonlinear devices, this method can be generalized and leads to the resolution of a system of nonlinear equations with, for example, a simple Newton Raphson algorithm.

Several test cases for electric and magnetic molecules will illustrate the usefulness of this state space FDTD approach. The passive molecules that lead, for instance, to the generalized Lorentz models for both the polarization and magnetization fields and the active molecules that lead, for instance, to the clamping circuit models of the polarization fields will be emphasized in our presentation.

Making Use of FDTD-PML in Electromagnetic Compatibility

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The Perfectly Matched Layer (PML) has been developed to simulate the infinite space surrounding finite-difference time-domain (FDTD) computational domains. In general, its performances are better than those of other absorbing boundary conditions (ABCs). It allows the size of the computational domain to be reduced and/or the dynamic range of the results to be increased. In Electromagnetic Compatibility (EMC) computations, the former improvement is the most useful. Contrary to other ABCs, the PML can be set very close to the scattering structure so that the PML-structure separation can be as short as only two FDTD cells.

As known, there are evanescent waves in the vicinity of scattering structures. The magnitude of such waves decreases with distance from the structure, on a length that is typically of the order of the size of the structure. For this reason, most ABCs must be set some distance from the structure, out of the evanescent region, because they cannot deal properly with evanescent waves. With the PML ABC, the problem is slightly more complex. In theory (in the continuous world), evanescent waves are absorbed without reflection by PMLs. In practice (in the discretized world), due to the discretization of space in FDTD cells, strongly evanescent waves are reflected by PMLs. But one can make this numerical reflection negligible by carefully designing the PML, in such a way that the PML can be set in the evanescent region, close to the scattering structure. The key parameters of the PML and the conditions to be satisfied by these parameters were found empirically, resulting in the black-box concept : in computer codes, the PML can be design by the code itself as a function of some parameters of the computation (size of the structure, duration of the computation).

The first part of the paper will briefly present the theory of absorption and reflection of evanescent waves by PMLs. The second part will describe the optimum PML and the conditions to be satisfied by its key parameters. The last part will present how we have made use of the PML ABC in a 3-D FDTD code primarily designed for EMC applications. In this code, free-space simulation is a black-box : the PML is set two cells from the structure of interest and its parameters are set by the code as functions of the problem to be solved. In consequence, making use of the code is easy, mainly because the critical choice of the structure-ABC separation is removed. Errors resulting from lack of vacuum around the structure are practically removed, so that reliable computations can be performed even by unpracticed users.

Implementation of Lumped Circuits in FDTD Codes

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A growing interest in the development of numerical tools in the electromagnetic domain has been observed these last ten years. Due to the increasing capabilities of computers, approaches such as FDTD are now able to deal with diffraction phenomena of waves by complex and more realistic structures [1,2]. On one other side, the CAD tools become more and more complex to model the behaviour of electronic circuits in a high frequency range [3].

The increasing integration of electronic components make very difficult to separate the study of the two parts quoted above. For exemple, in the patch active antennas area, the electronic circuits are implemented near the radiating element, then, the circuits of connexion can perturb the correct behaviour of the antenna. Consequently, modern electromagnetic softwares must be able to integrate all circuit components.In this paper, we introduce different ways for coupling FDTD codes with circuit tools. A survey of the different approaches recently published by other authors will show the different strategies for the coupling.

*A first way consists in including the electric scheme of circuit components inside cells. This was the first approach developed by Tolland [4]; it consists in computing the magnetic field circulation around the lumped element cells. This circulation corresponds to the total current flowing the cell : displacement current, current through the lumped elements.

*The second approach consists in coupling CAD softwares such as SPICE with the FDTD [5]. At every time step, the magnetic field circulation (total current) creates a current which acts as a current source in parrallel with the cell capacitance. the circuit is connected to the lumped circuit dipole then the dipole voltage is modified, this voltage is then transformed into an electric field and introduce inside FDTD code. Such an approach is very efficient and allows to model complex circuits thank to the data base of SPICE tool.

*Another way to take lumped circuits into account in to consider them on wires structures whereas inside cells. This can easily be made using thin wires model such the one developed by R. Holland . In such a model, it can be shown that each segment of the wire can be seen as a voltage source in series with an inductance. Than, it is easy to consider a complex dipole fed by a wire segment. In order to model the circuit behaviour, a state variable formalism has been developed . We will show that such a method coupled to a variable step Runge Kutta integration method is always stable even for strong discontinuities; no divergence have been observed.

All these approaches will be illustrated by some examples. A comparison of the advantadges and the drawbacks of each approach will also be made.

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Introduction of a New Model of Partially Magnetized Ferrite Material in a FDTD Code - Application to Non Saturated Ferrite Devices

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This paper outlines the FDTD (Finite Difference Time Domain) treatment of partially magnetized ferrites characterized by a new permeability tensor model recently publised [1].

A large number of non reciprocal devices such as isolators, circulators, or phase shifters include ferrites with an arbitrary magnetization state. Because of their complex geometry, ferrite devices do not generally accept analytical treatment. One solution consists in analyzing their behavior with numerical methods. Several authors [2], [3] have recently applied the FDTD (Finite Difference Time Domain) method to electromagnetic problems including saturated ferrites. Two main approaches are used. The first one is based on time domain discretization of both Maxwell's curl equations and Gilbert's equation of motion. The second method consists in introducting the ferrite material frequency characteristics in the FDTD algorithm after inverse Fourier transform and convolution. It requires a causal permability tensor, as the Polder tensor describing saturated ferrite material.

In case of partially magnetized ferrite the Gilbert's aquation is not valid and, if many permeability tensor models have been proposed to describe the behavior of ferrite, they were not available over a large frequency range and were not causal. Anew model, which is causal, has been published recently by Gelin-Berthou [1].

In this paper, devices with non saturated ferrites are treated by the FDTD method where the model of Gelin-Berthou is introduced using a convolution method. The causality of this model is verified and we explain how to include it in the FDTD algorithm. This approach is validated and we explain how to inlude it in the FDTD algorithm. This approach is validated on a resonant ferrite structure for which a modal study is possible and furthermore by the computation of an antenna with an unsaturated ferrite substrate.

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FDTD Simulation of Microwave Circuits with Nonlinear and Active Elements

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FDTD simulation of microwave circuits that include lumped elements is useful for structures where electromagnetic coupling, interference, and compatibility are important (C.N. Kuo, B. housmand, and T. Itoh, 'Full-wave analysis of packaged microwave circuits with active and nonlinear devices: an FDTD approach, 'IEEE trans. Microwave Theory and Techniques, vol. 45, no.5, pp. 819-826, May 1997). An example of such structures is a packaged large-signal microwave amplifier. For such a structure, the interaction of the microwave circuit with the housing structure can modify the designed performance. The simulation of the performance of this structure requires a full-wave analyses that is provided by the FDTD algorithm. The extension of the original FDTD algorithm to include lumped elements is well established (V. A. Thomas, M.E. Jones, M. Piket-May, A. Taflove, and E. Harrigan, 'The use of SPICE lumped circuits as sub-grid models for FDTD analysis,', IEEE Microwave and Guided Wave Lett., vol. 4, no. 5, pp. 141-143, May 1994; and C.N. Kuo, R.B. Wu, B. Housmand, and T. Itoh, 'Modeling of microwave active devices using the FDTD analysis based on the voltage-source approach', IEEE Microwave and Guided Wave Lett., vol. 6, no. 5, pp. 1-3, May 1995). In this extended algorithm, a device model is presented either in terms of terminal voltage or current. It is combined with the FDTD algorithm for the cells where the devices are present.

The current design rules for microwave planar structures are based on circuit theory models. In effect, the transmission lines are designed to operate at the dominant modes, and the discontinuity separations are such that the coupling of the higher order modes to the dominant modes is negligible. Such circuits are typically composed of transmission lines, lumped elements and tuning structures. For this type of structure, the full-wave analysis is potentially required only in areas of complex transitions such as a cross junction, or the location of lumped elements. Other approach reduces the computational requirements in term of memory and CPU time. In this talk, the application of the extended FDTD algorithm to a number of practical microwave structures which include active and nonlinear elements are presented. The savings in computational resources achieved by representing segments of the passive circuit structure by their equivalent circuit model is also illustrated.

Session E12
Friday, July 17, PM 13:40-17:40
Room K
Signal Processing
Chairs : S. Morvan

Target Enhancement for Marine Radar Video Signals by Spatial Frequency Filters

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This study is to develop methods to enhance target signals in the clutter environment for marine radar video signal processing by spatial frequency filters. Whereas a target signal is isolated in space and has stationary spatial intensity distribution over the object, the sea clutter extends over the broad area.

The first method is a matched filter whose transfer function is constructed from a target signal in the B-scope image. The processed B-scope image, the outût of the filter, results the enhanced intensity of target signal and the crosscorrelated, reduced clutters and other targets. The simulation of the two dimensional matched filter for the video signals collected by X-band marine radar shows the improvement of the signal-to-clutter ratio to be 2.5dB, typically for the false alarm rate 10^{-2}.

The second filter exploits the spectral difference in the subintervals. The spatial frequency spectrum can be divided into the low and high frequency components where each transforms onto the same amplitude for the target, but results the discrepancy for the clutter in its degree of maldistribution. The simulation to suppress the clutter by the degree of this discrepancy for the same B-scope image shows 2.0dB improvement in the signal-to-clutter ratio and the effect against the repetitive sea clutter.

These algorithms of the filters and the simulation results will be discussed atthe symposium.

Extracting the Frequency Dependence of Close Scatterers

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Extracting the frequency dependence of radar scatterers is a common task in Radar Cross Section analysis. This is usually achieved with signal processing tools like finite impulse response filters allowing filtering in the range domain. The usual procedure is to Inverse Fourier Transform the scattering coefficients from the frequency domain to the range domain, then to gate out the range cells that are not of interest by applying the filter, and finally to Fourier Transform the gated data back to frequency do
main.

However when range resolution is poor and when one wants to separate closely spaced scatterers, it becomes impossible to extract the exact feature since it is not deconvoluted in the range domain. We thus propose to use IIR techniques to overcome these difficulties.

The basic idea is to apply a high resolution analysis method on a short sliding frequency window. The range resolution on such a window is not good enough to separate each scatterer with a classical FFT. However, HR algorithms lead to correct estimates of the positions and amplitudes of these scatteres. Thus, by tracking the amplitude of a particular scatterer versus the central frequency of the window, one straightforwards obtains the frequency response of this scatterer.

This method is applied to estimate the frequency response of the creeping wave of a small sphere in a case where the creeping wave and the specular reflection belong to the same range cell. The results show very good agreement with theoretical response calculated with Mie series.

A Signal Processing Analogue of Phase Screen Scattering

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In this paper we evaluate the statistical properties of a filtered random phasor, where the filtering is described by an equation of the following form

$$S(t) = \lambda \int_{-\infty}^{t} dt' \exp[i\phi(t') + \lambda (t'-t) + i\omega (t'-t)] \qquad (1)$$

and ϕ is a real stationary random process. Considered from a signal processing point of view the problem is one of non-linear filtering of ϕ, which appears as an imaginary exponent within the integral. The integral expresses a linear filtering of the factor exp[iϕ], and is simply a bandpass Lorentzian filter of width λ and centre frequency ω. The non-linearity is strong when the excursions of ϕ are on the order of , or greater than, π. It is this case that we are predominantly concerned with in the present paper.

This kind of filtering arises in a number of situations of practical interest but the present investigation of its properties was stimulated by two rather different optical sensing techniques. The first is a diagnostic technique for semiconductor lasers based on heterodyne detection. The aim of the second technique is to enumerate the number of unresolved scattering objects which lie within an illuminated volume by analysing the statistics of the scattered radiation.

The purpose of the paper is to determine the statistical properties of the amplitude of S under different conditions and interpret the results and their implications in the light of previous work on phase screen scattering. In particular, the potential of the non-linear processing of ϕ implied by (1) for signal characterisation and information extraction will be highlighted. The present work contributes to the subject of phase screen scattering by extending earlier theoretical work to the case of an exponential aperture and by elucidating the evolution of the distribution of intensity fluctuations in the transition region through numerical simulation.

Corrected Monopulse Methods for Adaptive Arrays

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Adaptive beamforming (ABF) is not only used to restore the signal-to-noise ratio (SNR). After detection, angle estimation, e.g. by monopulse techniques, is required. The problem then is, that the adapted patterns may be distorted such that large errors in the monopulse estimates appear, in particular for jammers within the main beam region. For large arrays the number of channels for ABF has to be reduced for the reasons of cost. Two principles of reduction are possible: (a) to sum up the elements into subarrays and do ABF with subarray outputs, this is called ABF by direct subarray weighting (DSW), (b) to form complete sum and difference beams and generate in parallel auxiliary channels from the array, which are used in a generalised sidelobe canceller (GSLC) configuration. For the GSLC the main beam can be formed broadband at RF, for DSW all beams are formed at narrow band and digital. Both concepts have advantages and disadvantages, in particular with respect to main beam jamming. In [1] a monopulse correction technique was developed for ABF by DSW, which is valid for arbitrary sum and difference beams and for arbitrary subarrays. By properly defining the subarrays and weights, the GSLC can be formuled as DSW ABF. Therefore the correction formulas of [1] can also be applied for the GSLC, [2]. This paper is concerned with the performance of these corrected adaptive monopulse methods.

The statistical distribution of the unadapted monopulse ratio has been determined in [3]. This investigation was performed for arbitrary complex sum and difference beams. The results are therefore in principle applicable to the monopulse ratio R formed with adapted beams $R_\alpha = \Re\mathrm{eal}\{D_{adapt,\alpha}/S_{adapt}\}$, where $D_{adapt,\alpha}$ denotes the output of the adapted difference beam (a indicating azimuth or elevation) and S_{adapt} the adapted sum beam. In our case the azimuth and elevation difference beams are correlated and the results of [3] have to be generalised. In particular, we obtain the bias $\mathbf{b} = E\{\mathbf{R}|\eta\}$ and the covariance matrix $\mathbf{M} = \mathrm{cov}\{\mathbf{R}|\eta\}$, where h denotes a threshold which the sum channel has to exceed to avoid unreasonable monopulse estimates, i.e. the heavy tails of the distribution of the un-thresholded monopulse ratio. The corrected monopulse for DSW as well as for GSLC has the form $\mathbf{w} = \mathbf{w}_0 + \mathbf{C}^{-1}(\mathbf{R} - \mathbf{m})$, where w and w_0 denote the estimated direction and the antenna look direction, respectively (w has two components for azimuth and elevation). The bias correction vector m and the 2´2 slope correction matrix C are suitably determined, [1,2]. We obtain expressions for $E\{\mathbf{w}|\eta\} = \mathbf{w}_0 + \mathbf{C}^{-1}(\mathbf{b} - \mathbf{m})$ and $\mathrm{cov}\{\mathbf{w}|\eta\} = \mathbf{C}^{-1}\mathbf{M}\mathbf{C}^{-1}$ of the adapted corrected DSW and GSLC monopulse. We these results, we demonstrate the performance of GSLC and DSW monopulse for a large planar array with 32 subarrays. In particular, we show the dependence on the number of auxiliary channels, tapering of the beams for low sidelobes, and SNR.

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Fast Modeling of Induction Responses Using Fourier Analysis of Geometric Factor

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Interpretation of Induction logging requires fast modeling of the tool response in complex conductivity distributions. The low frequency approximation allows for linearizing the problem and introducing a geometric factor matrix (GFM). The GFM columns represent a functional basis for decomposing the induction tool responses regardless of the conductivity values. Each column describes a response of a certain formation block. If there are excessively many blocks, the GFM becomes poorly conditioned. This indicates that only few columns are required to reconstruct the entire matrix. We introduce a method of analyzing the linear dependencies in the GFM and finding a reduced comprehensive functional basis.

Traditionally, the way to analyze this type of data is by using the Singular Value Decomposition (SVD) algorithm. In spite of the numerical advantages for using the SVD, its use on large systems (with dimensions in excess of 10,000) is prohibitive when the computational speed is an issue. In that regard, the construction of a fast, approximative solution is a valuable alternative. We explored the possibility to transform and approximate the original large system using subsets of the most significant coefficients in the Fourier, Hartley and wavelet transforms. After approximating the system, the solution of the approximate system in transform space is constructed and then inverse transformed, yielding the approximate solution of the original system. The behavior of the solution for the approximate system and its convergence toward the true solution depend on a type of problem and the approximation level. This dependence was studied extensively to determine the feasibility of the method. The results are encouraging and the practical implementation of a suggested approach may result in a significant speed up of inversion techniques for induction logging.

An Efficient Approach for the Computation of the Modal Spectrum of Ridged Rectangular Waveguides

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Ridged waveguides have been recently used to simulate the effect of tuning screws present at several passive microwave structures, such as for instance inductively coupled rectangular waveguide filters [1], or dual mode filters [2]. The efficient design of these complex structures requires a very good knowledge of the modal spectrum of ridged waveguides considered. Traditionally, it has taken extensive computational efforts to obtain such modal spectrum with high precission, although recently a new method for solving this problem in a rigorous and efficient way has been proposed in [3]. This technique essentially consists of rewriting the Helmholtz equation in a form that gives rise to a linear matrix eigenvalue problem once the Galerkin procedure is used to obtain the modal solution. This algorithm also allows to compute straightforwardly the coupling coeffcients between the ridged waveguide and the corresponding rectangular waveguide without metal insertions, which can be very useful for the electromagnetic analysis of the structures mentioned before.

In this paper, an efficient implementation of the general method described in [3] for the particular case of ridged rectangular waveguides has been set up, thus reducing the computational cost and increasing the precission in the results obtained by solving analytically most of the integrals related to the practical application of the method. Furthermore, multiresolution analysis based on wavelets is also considered to obtain better approaches for electromagnetic fields in the vicinity of corners of ridge waveguides.

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The Numerical Method Using Operator Weights for Solution of Operator Equations Arising in Electromagnetic Problems

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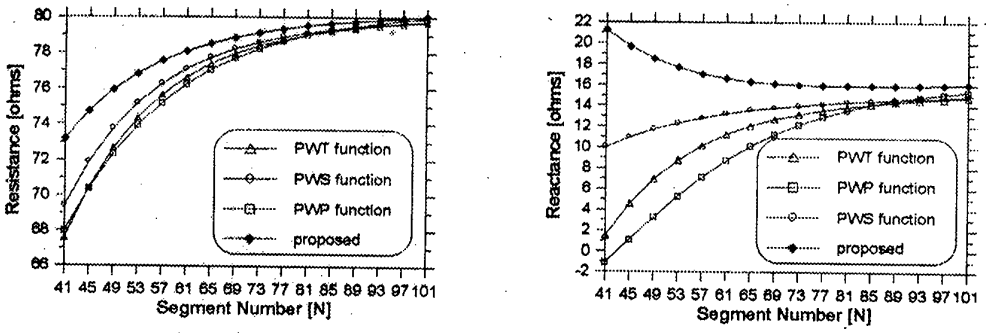
In this paper the numerical method using operator weights is presented for solution of operator equation arising in electromagnetic problems. The proposed method doesn't need basis functions and weighting functions. The concept of this method is that an operator of equation is approximated to the operator weights as if an integral operator can be approximated to integral weights in numerical integration. Consider operator equations of the inhomogeneous type L(f) = g where L is an operator, g is the excitation (known function), and f is the response (unknown function to be detrmined). Then L(f) is able to be approximated $L(f) \approx W_1f_1 + W_2f_2 \cdots + W_Nf_N$ where W_i are operator weights, f_i are unknown point values, and N is the number of segments. The above equation can be converted to the matrix form sinceg is known function. In this procedure, basis functions and weight functions are not defined.

The method of moments (MoM) is generally used to solve the operator equations of the inhomogeneous type. When MoM is applied, basis functions and weighting functions must be defined. If basis function and Weighting function are dedfined as continuous function, calculation of inner product is often difficult. For simplicity piecewise pulse (PWP) functions, piecewise triangle (PWT) functions, or piecewise sinusoidal (PWS) functions are used as basis functions and Dirac delta function as weighting functions. In this case, to reduce the interploration error the number of segments should be increased.

Fig. 1 shows the resistance and the reactance of the dipole antenna with the number of segments. For analysis the wave lenght λ is lm, the lenght of dipole antenna is 0.47λ, and radius of dipole antenna is 0.005λ. We can see that the method using operator weights obtains the higher convergence speed than the MoM using PWP, PWT, and PWS functions as basis functions.



(a) resistance (b) reactance

Fig. 1 Input Impedance of dipole antenna

Robust Pipe Recognition in Ground Penetrating Radar Data

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There is an increasing need to develop systems for the extraction of information about the underground, especially to plan safe works in urban environments, as well as for geologic, cultural heritage, and archeological purposes [1]. However, more and more quantities of data can be obtained by actual systems, like the Ground Penetrating Radar (GPR), whose analysis and interpretation is a very difficult task, due to noise and structural differences among the object typologies to be retrieved, and also among objects belonging to the same class. Therefore, it is stringent to work toward a detection system robust to noise as much as possible, not computationally intensive, and able to cope with pattern differences significant to field experts.

Robust image interpretation means first a robust denoising of the data, like the one obtained by a suitable wavelet analysis. As known, the idea behind "wavelet denoising" is that the noise can be removed via thresholding the coefficients of a wavelet decomposition of the original data [2]. If we assume that coefficients insignificant with respect to the threshold λ are likely due to noise, the only left question is which threshold is more useful. In this paper we choose the *soft-thresholding* approach, where λ is chosen as a function of the scale α of each wavelet subband (in particular, $\lambda(\alpha) = \sigma^2\sqrt{\alpha}$). The robustness and efficiency of the approach allows a better recognition of the pipe signature in the GPR data.

However, the task to extract these signatures remains quite difficult, since the theoretical hyperbolic shape due to the interaction between the incoming wave and a perfectly circular cylindric structure is actually slightly changed by geometrical and electrical differences between the model and the reality. To recover from these pattern recogniton errors, the use of neural networks is a *classical* choice [3]: the capabilitiy of neural nets, indeed, to mimic the behavior of the human brain in image interpretation, with high robustness to noise, is a optimal characteristic with respect to the problem to recognize signatures in GPR denoised data. To this aim, we used a very simple (but quite effective) backpropagation neural net, trrained with some of the signatures extracted from GPR measurements or computed by means of a simple model, and tested on actual data whose ground truth is available.

Therefore, by the joint use of wavelet analysis and neural network image interpretation, a robust approach to pipe signature detection has been developed, and tested by a comparison with manually analyzed GPR image data. The results are quite interesting, and show that the proposed approach is suitable for the first steps of an automatic processing chain for *on-field, real-time* analysis of the underground in urban environments, where pipe detection is of primary importance, in particular for commercial applications (e.g. service providers).

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Restoration of the Signal Form with Using of the Invariance Property

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In many practical problems, in particular, for underground penetration radar system designing the decision of incorrect problem of restoration of the true signal form on measured signal is necessary. By mathematics kind this problem is convolution of required signal s(t) with registration antenna system apparatus function or pulse characteristic g(t) :

$$\int_{-\infty}^{\infty} g(T)s(t-T)dT=u(t), \qquad (1)$$

where u(t) is target signal. Well-known methods for decision of this problem assumes, that g(t) is known. However in the many practical cases it strongly depends on many factors, is rather unstable or has a complexity kind. It make a large errors in the results. To exclude obvious definition of function g(t), frequently signal is restored by results of two measurements. For this purpose at first the apparatus function g(t) by results of the measurement u(t) as a result of the known source effect s(t) is determined, and then the solution of equation (1) is fined for any u(t). The accuracy of this method is also insufficient, because of it requires the exact knowledge of s(t) and u(t) form for "the trial response", that is exact initial measurement g(t) at known s(t) and u(t). At the same time the signal s(t) cannot be defined with a small error even in case of width of the directivity and registration system pulse characteristic, essentially distinguished from measurement signal form.

The decision algorithm of the signal restoration problem on the basis of the double signal measurement by a system with adjustable the amplitude-frequency characteristic (AFC) and the phase-frequency characteristic (PFC) invariance to AFC is resulted in the report. It is supposed, that of the measuring system in the working frequency band is stable, and the system twice registers the same signal s(t). Further the ratio (1) is decided in the frequency area.

Results of decision of the model problems of the true signal form restoration deformed by the pulsing characteristic of the elementary phase-invariant system as a diode controllable attenuator are resulted.

Thus, in case of the signal processing by the phase invariance system the solution of signal restoration problem is possible. This way can be used in case of impossibility of decision this problem by method of trial response, as well as by use of the two-channel systems with different AFC and identical PFC.

The Image's Segmentation on a Basis of a Fractals Dimension and Logic Linkage

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The image processing is the problem of segmentation, i.e. division them on area is one of the most difficult. The segmentation allows to allocate sites in limits of which the image limits homogeneous structure. If maxima on histogram of brightness the maxima of object and background are carried, reasonable methods of a threshold global choice i.e. for the image or local are known when the threshold is calculated for the image each point. A method of a threshold choice of a signal steepness point maximum is known. However if histogram of the image brightness have not only one modes, that is the low contrast image characteristic, the threshold processing is inefficient.

One of segmentation image attribute is meaning fractal dimension. Is established, that the images of natural landscapes and natural stages are characterized by size fractal dimension. We shall present an observable stage by a composition from the images of a background and object interesting us. Object and background are caused by not connected physical processes and can change with time current. The object can be both artificial and natural, however it has a set of steady attributes, allowing to separate it from a background. We shall present video signal as f(x, y) = S (x, y) + fc (x, y) Sb (x, y) + n (t), where S (E, y) - brightness of a object; Sb (xij, k) - brightness of a background fc (i, j) - weight function, describing absence of a background in a place of a presence of object; n (x, y) - a handicap as white noise.

The characteristics of a stage are object contrast - Target-to- background contrast (TBC) attitude a signal - handicap Signal-to-clutter ratio (SCR). Local fractal dimension of image FD.

In quality information of artificial objects attributes were accepted the relation two mutually perpendicular chords taking place through centre of the image P1 = Lmin/Lmax, quantity of sharp breaks a contour P2, curvature of a contour P3 = (qi/n, qi -m of vectors making a contour and have one direction, n - quantity elements in a contour. The integrated characteristic of the image was determined A=a1P1 + a2P2 + a3P3, where a1, a2 and a3 - weight factors of attributes, on the basis experiments were accepted a1 = a3 = 0.4, a2 = 0.2. The spent researches of the television images segmentation algorithm with "! till 0.02 and SCR=0.93 have shown attributes stability for allocation of artificial objects on complex background.

Atomic Functions and its Applications to Tasks of Signal Processing and Boudary Value Problems

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The theory of atomic functions has been presented in [1-3]. On the one hand atomic functions can be considered as infinitely smooth splines and on the other hand, in the opinion of a number of specialists, atomic functions, and approximations based on them were one of the ideological origins of so - called ''wavelets'' or ''ondelettes'', which have found widespread use recently (since 1985). Among other applications, wavelets are widely used in signal processing problems (or multiscale analysis) . Let us point out that in [1]in 1971, where , as pointed out above , the function up(x) was first introduced, it is proposed to describe a generalized function , i.e. , a continuous functional on the space of basic functions up($2^n \cdot x - k$). The relationship to wavelets is easily overlooked. A large number of mathematical methods for processing not only one- dimensional signals but also multidimensional (or images) has been developed on the basis of atomic functions.

We consider the following questions are of interest :

1- Finite and Rapidly Decreasing Smooth Functions as a Tool of Mathematical Signal Processing Methods.

2- The up(x) Functions, h_α, $Fup_n(x)$, and $\Xi_n(x)$ Functions.
3- Approximation Properties of Atomic Functions.
4- Generalized Taylor Series for Infinitely Differentiable Functions.
5- Using Atomic Functions for the Synthesis of CIC Filters.
6- Synthesis of Weighting Functions by Means of Atomic Functions.
7- Discretization and Interpolation of Signals Using Atomic Functions.
8- Image Reconstruction Using Deconvolution Windows Built from Atomic Functions.
9- Application of Atomic Functions for Solution of Direct and Inverse Boundary Value Problems.

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Session F09
Friday, July 17, PM 13:40-16:40
Room B/C
Antennas for Mobile Communication Systems

Organiser : T. B. Vu
Chairs : T. B. Vu, S. Choi

Variable Radiation Pattern of Helix Antennas

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1. Introduction

Two-wire or four-wire helical antennas, which are rod-shaped and space-saving and hence simple in structure, have recently been attracting attention as antennas to be used for mobile satellite communication base stations. The bifilar helical antenna shown in Fig.1(a) is of an enclosing structure with an external helix having a height H of 0.1(m) and a diameter D of 0.044(m) and an internal helix having a height H of 0.06(m) and a diameter D of 0.02(m); the helical antenna shown in Fig.1(b) is of a piggyback type having the structure given above with one or two turns of wire wound on a column, through the tip of which power is supplied.

2. Characteristics

Characteristics of a single unit is first described. Fig.2 shows radiation pattern of frequencies of 1525, 1575, and 1661MHz. Fig.3 shows radiation pattern in that case of Fig.1(a). The figure shows that the two turn unit exhibits a unilateral directivity characteristic. In other words, the figure shows that the internal helical elements strongly affects the single unit characteristics of the external helical element. It is clear, however, that the effect is not so strong in the case shown in Fig.1(b) as in the case shown in Fig.1(a). As a result, it is clear that the structure shown in Fig.1(b) is less affected by the internal helical element than the one shown in Fig.1(a) is.

3. Conclusion

As a result of examining the two types of helical antenna, an enclosing and the piggyback type, it has become clear that with an enclosing type, the characteristics of the external antenna are disturbed by the effects of the internal antenna element. As a result, it has turned out that the piggyback type provides better characteristics than a single unit does. In the future, the authors will examine simpler feeding methods and thereby consider antenna structures that will provide better characteristics.

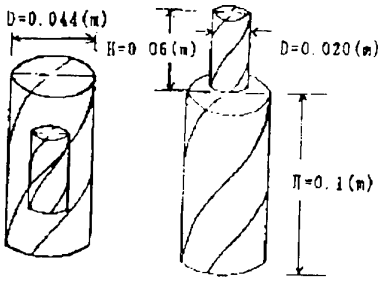
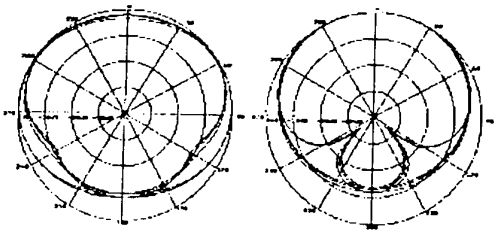


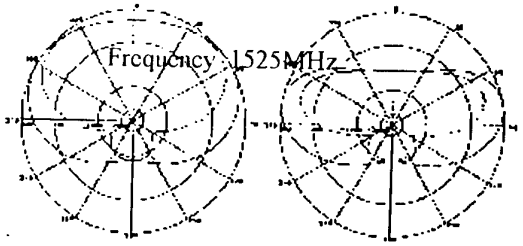
Fig.1 Construction of helical antenna



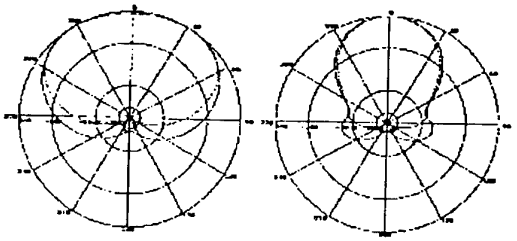
(a) D=0.044(m) (b) D=0.020(m)

Fig.2 Radiation pattern characteristics of a single unit

(a) one turns of wire Frequency 1525 MHz



(b) two turns of wire



(a) an enclosing type (b) a piggyback type

Fig.3 Radiation pattern of helical antenna

Adaptive Antenna Design for Indoor Radio PCS Systems

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In indoor wireless communications, signal propagation suffers from multipath fading and intersymbol interference (ISI), thus the transnmission data rate and capacities of systems are restricted. The use of adaptive antenna arrays for direct sequence code division multiple access (DS-CDMA) wireless communication systems has been suggested to overcome some of the above problems for the land mobile communications. However, in the applications involving indoor channel, dominant multipath can easily enter with a larger angle spread but with a smaller time spread. Thus the systems still suffer from fading having Rayleigh or Rician distributions within a chip duration due to limited resolution in the time domain.

This paper proposes an adaptive algorithm incorporating beamformer-RAKE structure to maximize the indoor CDMA based channel capacities by maximum ratio combining (MRC) of channel vectors within chip durations. Many adaptive beamforming algorithms usually require a priori knowledge of Angles of Arrival (AOAs) of the signals. MUSIC is one of the well known high resolution methods of estimating AOAs. However, it is only applicable in the scenarios in which the number of array elements is greater than the number of impinging signals. In indoor wireless scenario, the number of users and the generated multipath components usually far exceed the number of array elements. The spread spectrum technique, which allocates an individual signature code for each user, provides an opportunity to make use of MUSIC to estimate AOAs of the desired user and a few significant multipath components within one chip duration. When DS-CDMA spread spectrum systems are used, all users are code assigned with own signature sequence for transmitting over the channel. At the receiver a reference sequence is used to correlate the desired user to despread the spectrum and uncorrelate all the other users to respread the spectrum. The unwanted users become Gaussian noise after respreading. In addition, the multipath arising from the desired user having delays comparable to or greater than one symbol duration are also uncorrelated making it Gaussian noise as well. Thus, within one chip duration the existing information contains the desired signal and a few dominant multipath which are highly correlated. To apply MUSIC in such a scenario, spatial smoothing technique has to be used to produce a decorrelated covariance matrix. The signal to interference plus noise ratio (SINR) is then maximized by using optimized weight vectors at the output of each beamformer. Finally use of MRC technique is made to combine all dominant multipath components of the desired user.

The average BER for uplink DS-CDMA system for the indoor channel is analysed. The vector channel impulse response (VCIR) is obtained by simulation using a 3D ray tracing for multiuser indoor channels incorporating perfect power control. The computer simulations are compared for three cases: i) one element omnidirectional antenna, ii) eight element rectangular array using only one beamformer in which multipath components within one chip duration are not separated and iii) eight element rectangular array using parallel beamformers using spatially smoothed MUSIC. The results show that the adaptive antenna with one beamformer has average 12 dB improvement over a single-element receiver. More significantly, the adaptive antenna with spatially smoothed-parallel beamformers shows an improvement of 14 dB over the case with single beamformer having the same number of array elements.

Combined Adaptative Space-Time MMSE Receivers for Interference Suppression in DS/CDMA

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A main drawback in Direct-Sequence / Code-Division Multiple-Access (DS/CDMA) system is the near-far effect whereby a strong interfering signal can overwhelm a weak desired signal. An approach to eliminate the need for strict power control is to use the multi-user receiver [1]. However, the structure is too complex and requires substantial information about all other users. An alternative approach is to use the full-length and reduced-length minimum mean-squared error (MMSE) receivers [2,3], which only use the desired spreading code and need no information about other users. The MMSE receivers typically use the LMS tap update algorithm which is attractive due to simple implementation. One practical limitation of the full-length receiver is that the number of adaptive taps must be equal to the code length. The full-length MMSE receiver performs significantly better than the reduced-length (with less number of taps) MMSE receiver at the expense of impractically long training period for large processing gain. On the other hand, the latter converges faster at the expense of higher bit-error rate (BER).

The use of antenna arrays has been shown to increase system capacity [4]. In this paper, to improve the co-channel interference suppression capability of the existing MMSE receivers, two adaptive space-time full-length and reduced-length MMSE receivers are proposed. The adaptive array antenna adaptively updates its weights by using more reliable reference signals obtained from the adaptive MMSE receivers to take advantage of both space and time filtering. As long as a reference signal correlated with the desired signal can be obtained, the LMS updating algorithm of the antenna beamforms to track the desired signal and to suppress interference so as to maximize the array output signal-to-noise ratio (SNR). This paper will compare the performance of existing MMSE receivers with that of the new adaptive space-time MMSE receivers for both full-length and reduced-length cases.

Simulation results show that faster and more stable convergence with lower steady state MSE value are obtained for the two proposed systems in comparison with the existing systems. It indicates that the co-channel interference based on the cross-correlation among the spreading codes assigned to different users can be suppressed more effectively, in both the space and time domains. Considerable BER improvement is also obtained over the two existing receivers even at low desired SNR. It is also found that power control will also further enhance the performance of these two proposed receivers.

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Antenna Array for Signal Estimation in DS-CDMA Mobile Systems

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This paper presents a comparative study of four adaptive algorithms for implementing signal tracking and estimation in both the spatial and temporal domains. These four algorithms are TS, MEV, CMADD, and CMA.

The TS or training sequence algorithm employs MMSE (minimum mean squared error) criterion with the help of a training sequence. It has been proved that a TS equaliser has the best performance among these four algorithms. Moreover, a TS MMSE equaliser performs as the same as a zero-forcing equaliser if the freedom of the equaliser is big enough. The LMS algorithm can be employed, hence the calculation load is very low.

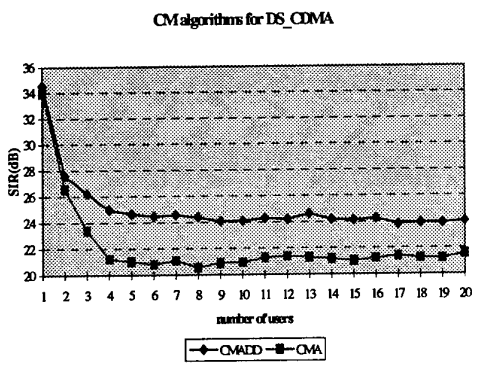
The MEV or maximum eigen-value algorithm is a blind equalisation techniques which also employs the MMSE criterion. However, it estimate the covariance matrix of the received data and the desired signal blindly. The eigen-vector decomposition is involved in the algorithm. Therefore, the calculation load is very heavy. Its performance is found to be close to that of the TS algorithm in the over load case. It can be shown that single-snapshot-updating is possible. Therefore, it can track fast moving targets.

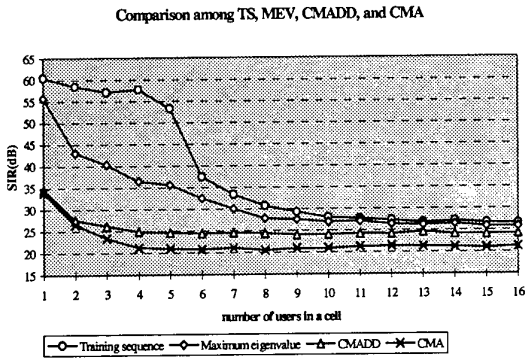
CMA and CMADD stand for constant modulus algorithm and decision-directed CMA respectively. The normal CMA algorithms can not be directly used in CDMA systems, because of many users sharing the same frequency band. The desired spreading code is combined with the normal CMA algorithm. It employs the fact that only the desired signal and its delayed version will be constant modulus signals after de-spreading.

Extensive simulations have been carried out to evaluate the performance of the algorithms. To simulate more realistic mobile environment, the DOAs and power are set randomly. Near-far problem and multipath fading are also considered in the simulations. Details are listed below, which summarised the performance in SIR against the number of user for a given number of sensors.

DS_CDMA: a spreading factor of 31
Number of users: 1 to 20
Number of paths: uniformly distributed between [5 15]
Delay time: uniformly distributed between [0 3*chip period]

Fading factor: 0.4 + j*0.4, 0.4 - j*0.5
DOA: uniformly distributed between [-60 60]
Signal power: power level is uniformly distributed [-5 +5]dB
White noise level: -15 db





A New Space-Time Equalizer for Mobile Communications

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We propose a new spatial-temporal equaliser whose advantage lies in its lower computational complexity and fair performance, compared with the conventional spatial-temporal equaliser.

Existing spatial-temporal equalisers (refereed as *ST1* hereafter) are formed by inserting an FIR filter on each sensor of the array[1]. The drawback of such a structured spatial-temporal equaliser is its high computational complexity, because the dimension of its coefficient vector is the product of the number of the array sensors N and the length M of the FIR filter.

The proposed spatial-temporal equaliser (refereed as the *ST2* hereafter) has a much simpler structure, where an N-element array is followed by an M-tap FIR filter. A single coefficient vector is formed by combining the array weight vector and the FIR filter's coefficient vector, and it is shown that the resulting *ST2* is able to simultaneously perform both spatial and temporal equalisations. It is clear that an $(N+M)$ *ST2* has much lower implementation complexity than an $(N \times M)$ *ST1* due to the smaller coefficient vector size, but at the same time the *ST2* has exactly the same degrees of expansion in both spatial and temporal domains as the *ST1*. Thus, the $(N+M)$ *ST2* should have the similar performance as the $(N \times M)$ *ST1*, since the maximum number of co-channel interference and inter-symbol interference that can be cancelled by an equaliser are determined by its degrees of expansion in spatial domain and temporal domain, respectively.

The performance of such an equaliser is verified by theoretical analysis and evaluated by computer simulations. It can be shown theoretically that the *ST2* equaliser is capable of completely eliminating both the inter-symbol interference and the co-channel interference by assuming only finite number of symbols being involved in the multipath fading. In this paper, the performance of the *ST1* and the *ST2* equaliser will be compared in terms of the output SNR and timing echo sensitivities by using Monte Carlo simulations. Our study demonstrates that this new spatial-temporal equaliser is an attractive alternative when system cost is equally critical as the performance. On the other hand, the simulation results also show that the *ST1* exhibits greater flexibility, with lesser sensitivity to timing phase errors.

Reference

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[1] In this paper, N represents the number of the array sensors & M is the length of the FIR filter

Antenna Size Reduction for Mobile Communication Systems

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Satellite-based mobile communication systems require a user terminal antenna that provides circular polarization and omnidirectionnal pattern. The resonant quadrifilar helix antenna is often presented as a very attractive candidate for such systems.

A low-cost printed quadrifilar helical antenna was previously presented by the authors [1], [2]. This antenna is obtained by printing the four antenna strips on a thin dielectric substrate and by wrapping it around a cylindrical support of electrical permittivity ε_0. An accurate numerical analysis of such an antenna was also presented in [1]. The method consists of transforming the printed antenna into an equivalent wire structure (using the concept of equivalent radius) and analysing this latter using a method of moments formulation for wire antennas.

The purpose of the presented work is to obtain significant size reduction of this printed quadrifilar helix by using either dielectric substrates of higher permittivity and/or electrically dense cylindrical cores. The extension of the method of analysis in order to take into account this new configuration is described.

A parametrical study is then presented: cylindrical cores of different thicknesses and permittivities are placed inside two S-band printed quadrifilar helical antennas. Experimental and theoretical results are shown.

Although it is based on quasistatic approximations, it will be seen that the method is still valid for high permittivity dielectric substrates and thick dielectric cores. Our results show that the inclusion of dielectric cores inside the antenna results, as usual, in a shift down of the operating frequency. A significant size reduction of the antenna is then expected.

References

[1] B. Desplanches, A. Sharaiha, C. Terret, "Numerical analysis of helical antennas backed by finite ground planes," *Microwave Opt. Tech. Lett.*, Vol. 15, No. 6, August 1997, pp 352-355.

[2] Sharaiha, C. Terret, J.P. Blot, "Printed quadrifilar resonant helix antenna with integrated feeding network," *Electron. Lett.*, Vol. 33, No. 4, February 1997, pp 256-257.

The Effects of Mutual Coupling and Diffraction for Adaptive Array Performance

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One of the important current areas of interest is mobile communications where fading and the delay time effects caused by multipath propagation degrades the communication quality. As a technique in these countermeasures adaptive array systems have been studied for mobile and base stations.

An ideal point antenna has often been used as a receiving element for the analysis of adaptive arrays where the effects of mutual coupling are ignored. Practically real antenna elements such as a dipole has to be used and the mutual coupling between antenna elements makes the array characteristics change. My group has studied adaptive arrays with the effects of mutual coupling between various wire elements and the effects of a finite ground plane which can be considered as a model of an antenna tower or an automobile roof

For the analysis of the adaptive arrays an electric-field integral equation is solved by the method of moments where a plane-wave incidence and 50ohm loads at the antenna inputs are assumed. Then the voltages at the antenna outputs are weighted in the adaptive array processor to increase the output signal to noise ratio. The geometrical theory of diffraction (GTD) is included in the method of moments (MOM) to consider the diffraction from the finite ground plane,

The performance of adaptive arrays with and without the effects of the mutual coupling and diffraction will be discussed. Linear, collinear and circular array characteristics are investigated. A dipole, a monopole and an inverted-F antenna are considered as an antenna element. The least-mean-square (LMS) and the power inversion algorithm for analog communications and the constant-modulus algorithm (CMA) for digital communications are studied.

A Circularly Polarized S-type Print Dipole Antenna

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Recently, circularly polarized antennas are used in many areas such as satellite communications, radars and so on. For a circularly polarized antenna element, linear antennas such as dipole, loop and helical antennas become major interest because they have a light and simple structure and a wider bandwidth compared with microstrip antennas.

In this paper, S-type print dipole antenna for circular polarization is proposed. The antenna consists of two rhombic loops terminated in a gap. Each loop is connected at the feed point and is on each surface of a dielectric plate. Therefore antenna configuration becomes simple S-type.

To begin with, S-type wire dipole antenna with a reflector is analyzed numerically. Antenna characteristics are calculated by the method of moments and compared measured data. In a result, by adjusting the rhombus vertex angle of the loop, the axial ratio bandwidth (less than or equal to 2 dB) of about 20% and the gain of about 10dBi are obtained. In addition, it is observed that the sense of circular polarization can be changed easily by switching gap positions.

Next S-type print dipole antenna with a reflector is analyzed by using FDTD. The results so far become similar to those of the S-type wire dipole antenna. More detailed analyses are now being continued.

Session G15
Friday, July 17, PM 13:40-14:40
Room M
Microwave Components IV
Chairs : H. Drissi

Microwave properties of ferroelectric (Ba,Sr)TiO_3 varactors at high microwave power and under video voltage pulses

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This work is devoted to evaluation of a tunability affected by electric field, dielectric losses, fast tuning capability, and power handling capability of ferroelectric (Ba,Sr)TiO_3 (BSTO) film varactors at microwaves (3-10 GHz). The small and large signal microwave (MW) properties of bulk BSTO ceramics have been investigated earlier [1], [2]. However, creation of electrically tunable MW devices employing low loss, thin ceramic BSTO ferroelectrics [3] spurs the MW investigation of planar BSTO structures at high MW power and under controlling voltage pulses. At present paper, the planar nonlinear capacitors based on high oriented thin (thickness t=0.2 μm) and polycrystalline thick (t=4 μm) BSTO films deposited onto $LaAlO_3$ and MgO substrates, respectively, were the subject of investigations at small and large levels of MW signal.

The investigations were performed on the base of resonant frequency and quality factor measurements of MW resonators incorporating BSTO film planar capacitors. Variations in resonance frequency and quality factor with MW pulsed power level or under controlling voltages (dc or pulsed) applied to the tunable capacitors enable changes in capacitance (C) and dielectric loss tangent (tanδ) to be determined [4], and response time of the ferroelectric elements could be established.

From results obtained it follows :

1) At L- and X-band frequencies and temperature T≅300 K a small MW signal capacitance tunability (K=C(U_{bias}=0 V)/C(U_{bias}=U_{max})) reached a value of 1.4 at applied dc bias electric field E_{dc}≅8 V/μm, and loss tangent ranged from 0.05 to 0.01 over bias electric field from 0-8 V/μm for the thin film BSTO capacitors; K≅2 at E_{dc}≅6 V/μm, and tanδ ranged from 0.05-0.02 at E_{dc}=0-6 V/μm for the thick film samples.

2) At frequencies about 10 GHz and T≅300 K a large MW signal BSTO capacitance and loss tangent were within 10% variation with MW electric field increase up to E_{MW}≅1 V/μm and E_{MW}≅0.5 V/μm for the thin and thick film capacitors, respectively. Note, besides a nonlinear phenomenon the heating of investigated ferroelectric films due to the MW energy dissipation is a main reason of alteration of the capacitance and MW dielectric losses.

3) The behavior of the both type of the BSTO film planar capacitors under video controlling pulses of a duration from 1 μs to 1 ms and front duration of 30 ns demonstrated a sharp variation of the capacitance with response time no more than 30 ns. However, an additional variation of the capacitance with a response time of ~20 μs was observed.

References

[1] V.K.Varadan, D.K.Ghodgaonkar et al. *Microwave J.* 1992. January, p.116.
[2] M.Di.Domenico, Jr., D.A.Johnson, R.H.Pantell. *J.Appl.Physics*. 1962.33 (5), p.1697.
[3] F.De Flaviis, N.G.Alexopoulos, O.M.Stafsudd. *IEEE Trans.on MTT*. 1997. 45(6), p.963.
[4] A.B.Kozyrev, V.N.Keis et al. *Microelectronic Engineering*. 1995. 29, p.257.

Optimization of Band Properties of a Short Impedance Vibrator on the Basis of the Complex Analysis

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The impedance vibrator theoretically and was experimentally studied in numerous work now already become classical. If the speech went about inductive character of a impedance load, the main purpose to which were aimed the researchers - reduction of the geometrical sizes of such aerials (or systems), i.e. increase of a electrical length; the individual purposes - updating of the diagrams of radiation of aerials and their passband. Now for whom for not a secret, that monopole (dipole) aerial of a shorter quarter (half) the lengths of a wave have a narrower working band of frequencies, lower efficiency, as well as change of other parameters. Occasionally in the seal there are the articles, where the authors try to optimize various parameters of impedance vibrators with the purpose to achieve maximally a possible working band of frequencies. But complex analysis, and consequently and complex optimization of band properties of a impedance vibrator in the literature was not marked. The authors of the article have tried to analyse band properties two-element director of aerials depending on óêî ðî ÷åí èÿ of a shoulder of a vibrator, thickness of a vibrator, position of a impedance load on a shoulder of a vibrator and gears shorten. At the same time they not take of resonant character of dependence of size of a impedance load from her position on a shoulder of a vibrator and as a impedance load of the first variant have taken discretic (ot) a element, that ñêî ðåé is acceptable only to vectorially long vibrators (i.e. with a capacitor load).

The purpose of work - research (complex analysis, optimization) band properties short inductive of a loaded vibrator depending on thickness and length of a vibrator, resistance fider, size and kind of a load (her position on a shoulder of a vibrator).

The analysis of a impedance vibrator was conducted on the basis of mathematical model published in the article, and confirmed in work. The mathematical model is conventional and under construction on the basis of the decision of a integrated equation of a type Pocklington concerning currents with exact singulare by a nucleus. Is applied new (named by the authors, numerical - analytical) method of account. The method has shown high accuracy and speed of account.

As boundary conditions is used impedance conditions Chukin-Leontovich.
The particular kind of a impedance load is not stipulated that to present the most common case. Only amplitude of a impedance load, the place of her accommodation on a shoulder of a vibrator and extent, so is stipulated. In limiting cases the impedance load can or completely take linen of a vibrator, or to be reduced to a dot element.

To demonstrate indissoluble interrelation of amplitude of a impedance from a position of a impedance load on a shoulder of a vibrator a package of the original programs is created, schedules of dependences of a factor of a standing wave of a voltage from these sizes are received. Three-measure the form of representation of this dependence permits qualitatively to evaluate interrelation of considered sizes.

Fourier Transformation of Electromagnetic Fields in to Opened Waveguided Structures in Classes of Distributions of Slow Growth

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Methods of solving the homogeneous and non-homogeneous boundary problems of electrodynamics in the compound mediums are advanced and justified by the help of integral Fourier transformation in classes of distributions (generalized functions) of slow growth. The technique of the reducing of problems on proper waves in the opened waveguided structures and the difraction problems of electromagnetic waves on dielectric bodies, restricted by coordinate lines and surfaces, to boundary value problems for analytical functions and to singular integral equations on borders of separation of mediums is developed, the decisions of which are considered in classes of generalized functions of slow growth.

The new form of the condition of radiation for leaving waves in the terms of a Fourier image is offered: the carrier of a Fourier image for leaving to infinity electromagnetic wave should belong to semi-space positive towards the direction of propagations of the wave.

The difraction problem for plane electromagnetic wave on a joint of four (in two-dimensioanl case) or eight (in three-dimensional case) rectangular wedges with different dielectric characteristics and the difraction problem of the guided mode on a joint of two planar dielectric waveguides (in the waveguide with step of the refraction index of film) are investigated in details.

Analytical expressions for the solutions of these two problems are received.

Session H11
Friday, July 17, PM 13:40-17:00
Room R02
Antenna and Signal Processing

Organiser : S. Skulkin
Chairs : S. Skulkin, J.F. Diouris

Binary Object Identification and Reconstruction by Using Neural Network Processing of Inverse Scattering Data

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The neural network approach has been proposed and tested for solving a special class of inverse scattering problems, the electromagnetic or acoustic characterization of the objects (defects or structures) embedded in stratified media. Three aspects of the problem have been considered.

The first one was based on the theory of the supervised learning of the multilayer perceptron. This theory has been reformulated for the case of identification of the object parameters from the scattering data. The aspect-limited, 2-D data configuration has been considered (L. Souriau, B. Duchene, D. Lesselier and R. E. Kleinman, Inverse Problems, 12, 1996, pp. 463-48 1). It was assumed that the test object is homogeneous with known constructive parameters so that the identification problem using multilayer perceptron consists of reconstructing the shape, location and physical properties of the object. A labeled dataset, each pattern of which being a pairs of input signals and target results was obtained during the numerical modeling the direct scattering problem for simple lossless inhomogeneities. As the input signals, the amplitudes and phases of the scattered field calculated with the account of the multiple scattering inside the medium under the investigation were used. The target results have represented a limited set of the parameters which described the characteristics of the inhomogeneities. For elliptical object, it were, in particular, the geometrical components of the translation and the rotation angle as well as the material parameters (M. Rychagov and B. Duch, URSI-97 Meeting, Montreal, Canada, July 13-18, 1997, p. 257).

On the second stage, the inverse scattering problem was reformulated from the point of view of optimization problem, which, in one's turn, has been solved by the utilization of the properties of Hopfield neural structure. It has been shown, that the fulfillment of some requirements to the network's architecture leads to the convergence of the dynamic process of reaching neural network's stable state. The linearized, Born-approximated problem has been considered. The high effectiveness of the developed Hopfield neural network based algorithm has been demonstrated in computer simulations. It has been also stated, that the ability of Hopfield neural architecture for high-effective data parallel processing can be implemented in the case of the multiple-frequency inverse scattering experiments.

Thirdly, a number of the specialized neural networks have been constructed with adequate realization of the Lippmann-Schwinger integral equation technique for the exact (with the account of multiple scattering) solution of the inverse scattering problem.

The questions of the determination of the optimal design parameters for the developed neural networks as well as the optimal characteristics of the inverse scattering experiments from the point of view of neural network data processing have been also analyzed.

Robust Beamforming in Adaptive Antenna Arrays

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In this paper, we present a tutorial on robust narrowband adaptive arrays. The following types of robustness are addressed :

1) against signal mismatch,

2) against perturbations of sensor positions,

3) against the lost of jammer and signal coherence along the aperture (A.B. Gershman, V.I. Turchin, and V.A. Zverev, IEEE Trans., vol. SP-43, pp. 2249-2257, Oct. 1995),

4) against wideband interferences (provided array implementation remains narrowband) (A.B. Gershman, G.V. Serebryakov, and J.F. Boehme, IEEE Trans., vol. AP-44, pp. 361-367, March 1996),

5) against rapidly moving (A.B. Gershman, G.V. Serebryakov, and J.F. Boehme, IEEE Trans., vol. AP-44, pp. 361-367, March 1996.) (A.B. Gershman, U. Nickel, and J.F. Boehme, IEEE Trans., vol. SP-45, pp. 1878-1885, July 1997.) and fluctuating jammers (A.B. Gershman and J.F. Boehme, Proc. 25 General Assembly of URSI, Lille, 1996).

The first two types of robustness are strongly needed in various applications including sonar, radar, seismology, and communications. The robust adaptive beamformers are usually designed using either point/derivative constraints in the signal direction or other constraint types. Another approach to robustness against wrong signal positioning is the eigenstructure-based adaptive beamformer (W.S. Youn, and C.K. Un, IEEE Trans., vol. SP-42, pp. 1543-1547, June 1994).

The robustness against jammer and signal coherence losses is necessary for very large arrays, especially in sonar, radioastronomy, and seismology. The practical solution to this problem is a combining of both short and long apertures for jammer suppression via partitioning the antenna array in overlapped subarrays. Another promising approach is the so-called quadratic processing (D.R. Morgan and T.M. Smith, JASA, vol. 87, pp. 737-747, Feb. 1988).

The robustness against wideband and rapidly moving jammers is one of the main problems in sonar, radar, and communications. Jammer motion is known to bring the interfering sources out of the sharp notches of the adapted pattern. The same phenomenon may occur due to a rapidly moving antenna platform, and in the presence of wideband and frequency hopped (fluctuated) interfering signals.

The main idea of robust adaptive beamforming in this case is the artificial broadening of null width in the jammer directions. For this purpose, either data-dependent derivative constraints are imposed, or adaptive allocation of beamformer degrees of freedom is exploited.

Properties of Polarisation Components of Transient Near-Field Radiated from a Parabolic Reflector Antenna

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A number of applications require to calculate radiation of a short pulses at different distances before the reflector. Some questions of the theory of an impulse radiating antenna (IRA) was given by Carl E. Baum and others (C. E. Baum, in book U-WB, SP Electromagnetics, Plenum Press, pp.139-147, 1993; D.V. Giri and C. E. Baum, Sensor and Simulation note 365, February 2 1994.). IRA, usually considered in those papers, consists of a conical TEM feed that attaches to a reflector antenna.

Another technique to calculate transient fields in acoustic approximation radiated from circular planar aperture was described in (S. P. Skulkin, V. I. Turchin, Proc. EUROEM'94 Symposium, France, pp. 1498-1504, 1994). However some applications require to have more accurate space-time distributions of near-field. In many cases it is important to describe the transient fields from parabolic reflector antennas taking into account the polarization effects and the shape of the antenna.

The paper based on the method of transient field calculation (S. P. Skulkin, V. I. Turchin, in book U-WB, SP Electromagnetics, Plenum Press, 1997). Here we use the assumption that a short pulse is radiated by a small feed (electrical dipole) that attaches to a reflector antenna. We also assume that the antenna diameter is much more than the maximal wavelength respective to the minimal frequency of the pulse spectrum. In this case the reflector surface current can be calculated only by the use of the feed magnetic field.

The strict formulas were obtained for three polarization components of field in the half-space before the antenna. We compare the component forms, magnitudes and discuss their properties. More over we compare calculation results for parabolic reflector, circular plane aperture and results of measurements of transient fields from a parabolic reflector antenna.

We show that each of the polarisation components includes several pulses. For the basic polarisation component the first pulse is shortest and of maximal amplitude. We illustrate that the response from the parabolic reflector is more durable than the response from the planar aperture. More over the amplitudes of the second and third pulses for the parabolic reflector are less than those for the planar aperture.

Basics of Low-cost Time-Domain Antenna Measurements and Experience of Antenna Measurements without Unechoic Chambers

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The basic idea of low-cost time-domain measurements is that antenna under test is radiated by a short electromagnetic pulse from different directions. The nature of electromagnetic pulse is that it is spatially concentrated. This allows one to separate antenna response excited by pulse from responses excited by its' reflections with a help of time window. This is equivalent to existence of unechoic area around antenna under test. The size of this unechoic area depends on the length of antenna impulse response, distance between antenna under test and pulse radiating antenna, distance between both antennas and reflecting surface, etc. Test equipment records a set of antenna impulse responses and then calculates different antenna parameters (including directivity pattern, phase pattern, gain, etc.). Signal processing includes blanking of reflections with a help of time windows of different shapes, calculation of each impulse response spectrum, calculation and smoothing of antenna parameters such as gain, directivity, antenna pattern, phase pattern, etc.

Another feature of time-domain measurements is that each complex antenna usually has it's "characteristic" pulse responses corresponding to some directions. These «characteristic» responses look like a set of easily locatable responses of individual antenna elements. This makes it possible to locate failed antenna elements by comparing reference "characteristic" response with a real one. In some specific cases this feature allows even to tune antenna array during field test.

The measurements system consists from a short pulse generator; radiating antenna; probe; antenna under test (including turntable); digital oscilloscope and computer. Software running at computer controls through control unit antenna turntable subsystem and digital oscilloscope. For each antenna position software records an antenna under test response. To record the response oscilloscope drives a pulse generator, which forms a short pulse radiated through radiating antenna. Data from oscilloscope is sent to computer via data acquisition hardware. Reference antenna is used for system calibration in order to determine time window size. After whole measurement cycle computer can display or store calculated antenna patterns in a database. Software also allows displaying any recorded pulse response for the purpose of field diagnostics.

Typical time-domain antenna measurements system has the following parameters:

Frequency range	100 MHz - 32 GHz
Dynamic band of directivity pattern measurements	more than 60dB
Directivity measurements error	less than 0.5 dB
Dynamic band of antenna gain measurements	more than 60dB
Antenna gain measurement error	less than 0.5 dB

Large practical experience of MERA engineers with many time-domain measurement system installations proved high efficiency of this method.

Antenna Charge Model and it's Application to Wire Antenna Synthesis

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The basic idea of wire antenna charge model is very simple: When wire antenna is excited by a very short current pulse an excitation area is condensed in one or few small antenna areas. With a time position of these "excitation areas" changes, they are moving along antenna wires. These moving "excitation areas" can be considered as point charges and an electromagnetic field of antenna can be calculated as a sum of EM fields radiated by those charges.

Representation of radiation field of wire antenna as a sum of fields of moving charges is an essence of charge model. Unfortunately authors did not succeed to derive this model from Maxwell equations or integral equations, so we can not theoretically derive the accuracy of this model. Authors conducted a set of experiments, frequency domain and time-domain digital analysis and computer modeling with different wire antennas and come to a conclusion that this model is quite accurate for a majority of wire antenna types. A set of charts proving this conclusion will be presented during the conference. One of most interesting applications of charge model is a synthesis of wire antennas by given antenna pattern. The most simple and obvious example is a synthesis of symmetric wire antenna consisting of 2 wires excited by a current source on one side with a matched load on the other side. For a charge moving in *xoy* plane a far radiation field *E* can be presented as:

$$\frac{E_x(\tau)}{2} = -\frac{\mu}{4\pi R}\frac{d^2x(\tau)}{d\tau^2}$$

Let us note that Ex and Ey (x and y components of electromagnetic field) can be given independently. The *R* is a distance between observation point and excitation point and *x(t)* is a trajectory of charge movement. Knowing *E(t)* , which is a pulse antenna response, we can derive the velocity of charge movement *V(t)* where c is a speed of light.

$$V_x(t) = -\frac{2\pi R}{\mu}\int_0^t E_x(\xi)d\xi \qquad V_y(t) = \sqrt{c^2 - V_x^2(t)}$$

and trajectory of charge movement *x(t)*The above equations has the following physical limitations:

$$x(t) = \int_0^t V_x(\xi_1)d\xi_1 \qquad y(t) = \int_0^t V_y(\xi_1)d\xi_1 \qquad |V_x| \le c$$

$$\int_{t_0}^{\xi_1}\int_0^{\xi_1} E(\xi)d\xi d\xi_1 = 0$$

The above equations can also be generalized for a non-plane antenna.

Few practical examples including wide-bandwidth antenna and frequency-modulated signal antenna will be presented by authors during the conference. Further details can be found in author's book "Analyses of processes of radiation and reception of pulse signals in time domain" – Moscow,: Rikel, Radio i Sviaz, 1996.

Bi-Polar Near-Field Antenna Measurements With Synthesized Short Radio Pulse

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The ground-based facility for near field antenna measurements was created some years ago in NIRFI (Nizhny Novgorod). This facility is intended to model the facility for ground tests of transformed space antennas.

During measurements a test antenna is directed to zenith and is rotated slowly around azimuth axis. The probe is placed at the end of horizontal arm of the scanner and is rotated continuously over circular arc above the antenna axis with velocity up to 15 circles per minute. The probe rotation plane is about 15 meters over the ground. Length of the scanner arm is 7.5 meters. The probe is used in radiation mode, test antenna receives this signal. An advantage of above mechanical scheme (now called "bi-polar") is the stability of antenna form during measurements through its elevation immobility. Besides, an absence of VHF-cable twists allows to realize the high accuracy of phase measurements.

The report considers a mirror parabolic antenna near-field, which is synthesized by measurements at a discrete number of frequencies with the following Fourier transformation of data into time domain, where separation of the signal components with different propagation occurs. Identification of these components taking into account the geometry of the measurement facility and the inverse Fourier transformation of a part of them allows us to define more accurately the antenna near field, as well as to define the interference field. The efficiency of such measurements is defined first of all by the band and the discrete of frequency variation chosen.

Feasibilities of the above methodics were investigated for NIRFI near field measurement facility. Synthesized signal of the antenna near field was experimentally investigated in the time range up to 500 ns with discrete about one ns, that permits us to identify paths and to determine levels of the signal being multireflected between antenna and scanner elements. An effect of these reflection on the far-field antenna characteristics was estimated using the restored distribution of the signal components on the measurement plane.

Inclusion of Constant Electromagnetic Power into Oscillating Circuit with Unsettled Dielectric Parameters in Condensor

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This paper contains the continuation of previous authoric researches (General Assembly URSI, Lille, France, Abstracts, p.192, 1996 PIERS-97, Cambridge, MA, USA, Proc., p.89).

A voltage step passing throughout the circuit of resistance, inductance and condensor with dielectric is studied here. Using the transient polarization expression obtained in previous works and we get integral-differential equation for the field in the condensor. For the Laplace transformation of the field the equation is reduced to an algebraic equation of fourth power. Its solution has an exact inverse Laplace transformation. The resulting establishment is desirable by the sum of the five terms. The first term is the established field in the condensor, the four others desirable the type of the establishment process.

There are three kinds of the establishment process:

- 1. All four terms are real ones and are four exponents with negative power.
- 2.Two terms are real functions of time (exponential attenuation), two others are complexconjugate ones (attenuation with oscillations)
- 3.Four terms form two pairs of complex conjugate terms (two attenuations with oscillations). These kinds are conditioned with the correlation between the time constant of the condensor without dielectric and ration between resistance.

The numerical calculations highlight these dependencies.

Electromagnetic Wave Scattering at Higher Harmonics by Antennas with a Nonlinear Load

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The main cause of nonlinear effects in electromagnetic wave scattering by metallic constructions is the presence of different mechanical connections (adjoining contacts of different metals, welded junctions, etc.). The presence of such nonlinearities of the objects leads to the spectral variations of a scattered signal, that can be of useful applications. The review (Kuznetsov, A.S. and Kutin, G.I. (1985) Zarubezhnaya electronica, 4, 41--53) presents a list of patents on the practical use of the effect on nonlinear electromagnetic wave scattering.

As a model of the nonlinear scatterer, dipoles or loops are often used which are loaded on local nonlinear element (for example, diod). The present report is devoted to experimental and theoretical investigations of nonlinear radiowave scattering by various antenna systems consisting of definite number of dipoles or loops. Here we consider stationary processes in the approximation of a weak nonlinearity that permits us to restrict ourselves in the spectrum field representation by the account of only the second and third harmonics.

We have considered the plane electromagnetic wave scattering by :

- a system of two or four parallel nonlinear oscillators. The dependence of the radiation pattern on the distance between the oscillators and nonlinear load location is investigated.
- oscillators disposed in mutually orthogonal planes. Some polarization features have been discussed for the back field scattering at higher harmonics which were absent in the field scattered at the fundamental frequency.
- parallel loops containing a semiconductor diod.
- two parallel loops or oscillators in the case when nonlinear load is only one of them. The main attention is paid here to the analysis of the back scattered field as dependent on the distance between scatterers , load location and scatterers length.

Also we have studied the influence of an air-dielectric boundary on the scattered field at higher harmonics of an oscillator and loop (with the diod) located near the interface. The growth of the scattered signal level is noted at the limits of the quasi-static zone loop location in the dielectric with an increase of the distance between the scatterer and the boundary. With a further increase of this distance the indicated dependence has an oscillating character.

The experimental measurements in all mentioned cases have been carried out under field conditions at the special automated facility. The experimental data and the corresponding theoretical calculations are in a qualitative and quantitative agreement. The investigations carried out can provide the solution of such problems as: development of highly efficient device-markers, for example, for rescure works on the aquatory; construction of technical facilities for the search of the place of aviation crushes; creation of small-scale devices with the given response for the sounding signal and a high Q-factor; the use of an effect of biological objects on the nonlinear scattering waves by the domestic electronics for the remote control.

Statistical Aspects of the Theory of Antenna Measurements

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In the report, being of a review nature, complex of questions, connected with the influence of random tool errors on potentialities of a holographic method (HM) of measurement of the antenna parameters is considered. It is marked, that the solution of similar questions is based on use of the apparatus and results of the statistical antenna theory (SAT) - theory of antennas with the random sources (Y.S. Shifrin, Statistical Antenna Theory, Golem Press, Boulder, USA). Direct and inverse problems of the statistical theory of antenna measurements (STAM) are formulated. The aim of the direct problem is to determine potentialities of the used in HM equipment with inherent to it random errors of the field measurement to restore radiation pattern (RP) of the antenna. Or else, in direct problems it is necessary to establish area of applicability of the used measuring equipment at given accuracy of RP restoration. The inverse problem consists in formulation of the requirements to the designed for HM measuring equipment by given accuracy of RP restoration. Both direct and inverse problems of STAM can be divided into internal and external ones.

Definitions of direct and inverse internal and external problems are given, their features in comparison with similar problems in general SAT are specified (Y.S. Shifrin, Sov. Journal of Com. Techn. and Electr., N 9, 1991, pp.32-49). The probable approaches to solution of specified problems and arising here difficulties, especially for inverse problems, are discussed. When solving direct and inverse problems of STAM a rather essential question is the one about an accuracy of RP restoration, i.e. question about "criterion of proximity" of restored and true RPs. When choosing the criterion of proximity for RPs two approaches are possible. The first approach is based on the investigation of a possible (or permissible) spread of restored RP relatively true RP in separate angular directions (the local criterion). At the second approach a spread of restored RP (as a function) relative to true one in a certain angular sector (the integral criterion) is studied. It is marked, that depending on chosen criterion of proximity of RPs the statement of external problems of STAM will be different. Accordingly, we shall obtain different solutions of these problems, i.e. different estimation of potentialities of the used equipment or requirements to it when designing. When choosing the criterion of proximity, the second approach seems to be more correct one. For this approach the typical formulations of direct and inverse external problems are given, methods of their analysis are pointed out, formulas and plots illustrating results of the external problems solution are given. Cases are considered, when measurement (registration) of the near field is made on plane and cylindrical surfaces, in the aperture of the antenna and in its Fresnel zone. A number of qualitatively interesting results are obtained. In particular, it is shown, that when using the Fresnel zone for registration of the field, the requirements to measuring means appear to be more rigid, than at measurement of the field in the antenna aperture. Later on in the report HM statistical aspects of restoration not of RP are considered, but of some parameters connected with it, namely, of RP width, gain etc. It is marked, that commonly these problems are solved easier and the requirements to the accuracy of the equipment appear to be less rigid.

In conclusion of the report a number of urgent directions of STAM development are specified. It is also marked, that the number of STAM statements developed with reference to HM, can be used when considering statistical aspects of the collimator method of the antenna parameters measurement too.

J. I. P. R. 4 - Session I10

Room 200

Friday, July 16, PM 13:40-17:20

Polarization Effects Modeling by Scattering Radiowaves and Surfaces

Organiser : A.I. Kozlov

Chairs : A.I. Kozlov and A.I. Logvin

Modeling of Earth-Based Target Radarobservations in the Relation to the Surface Characteristics

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At a bearing of ground driven radar objects the essential influence to a fluctuation of angular noise influences re-reflection of radar signals from a laying surface. Because from large variety of electrical properties and structure of earthly surfaces, the exact decision of a problem of determination of the reflecting characteristics by methods of a electrodynamics, is practically impossible. It requires the statistical description of a surface.

In work modules of mirror and diffuse reflection coefficients were analysed. This coefficient communicates with surface ordinates dispersion σ^2, mirror reflection angle γ and correlation radius of surface β.

Conducted analysis has shown, that the mathematical expectation of a mirror refection coefficient represents the monotone function α and γ, these values decreasing with growth. The family curve, describing mirror reflection coefficient on horizontal polarization, is a little above than similar family for vertical polarization. It is explained by dependence of a mirror reflection coefficient on polarization of a radiating wave.

The mathematical expectation of a module of a diffuse reflection coefficient essentially depends from σ^2, β and reflection angle from « brilliant » of points.

The knowledge of mirror and diffuse reflection coefficients enable to calculate complex amplitude of reflected signal.

The modeling was conducted for object, driven on dirt way and thin crust of ice over snow in direction on radar station at length of wave 8 mm. The analysis of received results has shown, that at movement of object on a snow thin crust of ice over snow the average significance of amplitude of a signal exceeds similar value, appropriate dirt way. An increase of speed of object results in reduction of dispersion of a reflected signal.

The conducted modeling has given a opportunity to receive absolute significance of angular errors of a bearing.

An Investigation of the Returned Polarization Characteristics of Terrain

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As new problems arise in the field monitoring of earth the requirements imposed on collection, processing, storage and representation of geoinformation become more strict. These requirements suggest the use of the new generation of remote probing systems, such as multipolarization radars. To increase the efficiency of discrimination of the types of probed terrain with the help of polarization processing of returned signals, one must increase the amount of information about the target.

Statistical characteristics of the polarization scattering matrix element values at the cophasal basis HH-VV calculated using experimental data obtained with the help of the SIR C radar for various areas of the terrain, are discussed in this report. The calculations have been carried out for two frequency ranges (L & C). The effect of some parameters such as the amount and type of biomass, the intensity of waves on the surface of water and the level of unevenness of plowed fields is determined. The use of Bayes criterion for the radar target discrimination using two-dimensional density of distribution is presented. Also this report suggests classification of radar targets according to scattering matrix invariants: proper values of $\lambda 1$, $\lambda 2$ and coefficient of anisotropy q. These values are characterized by a significant property: when rotating the target polarization basis they do not vary.

Using the scattering matrix element values obtained experimentally in cophasal basis HH-VV there have been calculated densities of probability distribution, mean value and standard deviation of $\lambda 1$ and $\lambda 2$ values and coefficient of anisotropy q for various areas of the terrain at two wavelengths of 23 cm and 5.6 cm.

Employing the rules of conversion of scattering matrix elements when varying polarization parameters, the images in circular, cophasal and affine basis ,in proper number values and coefficient of anisotropy were obtained. The differences between individual objects on the terrain were determined using the images obtained.

Classification of Radar Targets According to the Scattering Matrix Invariants

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The radar targets scattering characteristics are always presented in a definite polarization basis. Variations in the polarization basis parameters leads to variations in the numerical values of object scattering characteristics, and this is the main drawback of the matrix description method.

This report suggests classification of radar targets according to scattering matrix invariants: proper values of λ_1, λ_2 and coefficient anisotropy q. These values are characterized by a significant property: when rotating the target polarization basis they do not vary.

Using the scattering matrix element values obtained experimentally in cophasal basis HH-VV there have being calculated densities of probability distribution, mean value and standard deviation of λ_1, λ_2 and coefficient anisotropy q for various areas of the terrain at two wavelengths of 23 and 5.6 cm.

Classification of the investigated areas according to the degree of their polarization anisotropy has been carried out. An analysis of variation in statistical characteristics of the values of λ_1 and λ_2 and coefficient anisotropy q when varying the wavelength has been executed.

Radar images of the terrain using proper number values and coefficient of anisotropy were obtained. They were compared with radar images made in other bases.

There were investigated some other polarization invariants: the scattering matrix determinant det S and sum of squared absolute values of its elements.

The Increase of Radar Contrast by Polarization Processing Methods

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During processing of remote probing data, in addition to filtering, the polarization processing methods can be successfully used.

Radar targets are described through scattering matrices, the elements of which depend on the polarization basis parameters: polarization ratio angle and phase angle of field component shift. A change in the polarization basis leads to the change in the scattering matrix element numerical values.

There is one polarization basis where the difference between the scattering matrix elements of two specific targets will be maximal. The parameters γ and ψ will characterize the optimal polarization of discrimination.

This report presents formulas describing the conversion of the scattering matrix elements in relation to the polarization basis parameters γ and ψ.

$S'ij = F (Sij, \gamma,\psi)$, where $S'ij$ and Sij are statistical scattering matrices in the new basis and old basis respectively.

Using the scattering matrix element values obtained experimentally in cophasal basis HH-VV, there have been calculated the polarization basis parameters in order to get the maximum radar contrast for some types of terrain in the L (λ= 23 cm) and C (λ= 5.6 cm) ranges: coniferous and deciduous forests, smooth water surface and plowed field, grassy and plowed fields.

The degrees of discrimination in different initial bases, proper and cophasal HH-VV have been compared.

This report also presents relationships for density of probability distribution of the scattering matrix elements as well as portions of radar images before and after polarization discrimination. The effect of the scattering matrix parameters on their radar discrimination is showed.

Electrodynamic Modeling of Angular Noise in View Radiowave Polarization

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At a hearings of the radar target the important significance has accuracy of) of the target coordinates. There is a series of some algorithms of increase of accuracy of a bearings, using model of point-to-point target. However these algorithms do not take into account features of the extended target and conditions of radiowave propagation. For a estimation of reliability of accuracy of the statistical characteristics of angular noise of ground objects are necessary. It can be made helping of electrodynamic modeling. Such modeling should take into account depolarizating properties separate "bnlliant" of points. Such kind of modeling enables to investigate influence of architecture of objects, changes of effect of a microstructure of a district, rereflections from a laying surface and series of other factors the statistical characteristics of a bearing errors.

Under the term "the electrodynamic modeling" is understood process of reception of current significances of angular noise at the help of physical measurements of the statistical characteristics of a scattering of "brilliant" points of objects at various of signals polarizations. This process is earned out in a combination to mathematical modeling of parameters of movement of ground driven object at the account of reflections from laying surfaces. The basic difference of this method of modeling from known naturally-mathematical and physico-mathematical methods consists that it takes into account a depolarization of a rejected signal, occurring at reflection, from "brilliant" of points.

The problem of digital modeling of current significances of angular noise of driven objects is reduced to the numerical decision of a system of quasistationary nonlinear differential equations.

In the report a technique of realization of modeling is resulted. The digital modeling of revolting effects of a microstructure of a surface was decided by a method of a forming filter.

The conducted modeling has given a opportunity to receive normalized spectral density of distribution logitudinaly - angular and vertical fluctuations of a case of driven object at movement it with various speeds on a dirt way. The analysis has shown, that the most high-frequency The part of a spectrum arises owing to logitudinaly angular fluctuations, and the maximum of spectral density of probability at change of speed of movement is concentrated m a range of 0,2-1,0 Hz. The knowledge of current significances of angles and moves of a centre of weights permits to determine a current foreshortening of object in some given system of coordinates, described angles of a bearing and elevation. Besides it enables to determine current coordinates "brilliant" of points of object in a system of coordinates, connected with antenna of the radar station.

About Oportunities of the Radar Targets Detection by on Polarizable Anisotropy Index

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The polarizable anisotropy index of the radar target can be used for the decision of detection problems of these targets on a background of interfering reflections from laying surfaces. For the decision of this problem it is necessary to know the statistical characteristics of a polarizable anisotropy index. In work appropriate probability density function of a polarizable anisotropy index is received, the analysis has shown, that this density essentially depends on a correlation index of orthogonal components and background asymmetry degree. Thus the mathematical expectation of a polarizable anisotropy index does not practically depend on a correlation index of R at small significances of an asymmetry index -*r* of a background (r<0,25). The specified dependence begins self to display at the significances r>0,5.

Leaning on knowledge of probabilities distribution function of polarizable anisotropy index, in work calculate probabilities of correct detection for various parameters r and R for two cases of construction of radar station: single-channel and two-channel on polarization.

For radar station with single-channel on polarization the correct detection probability of the target is determined only by the relation a signal/background on a input of a radar receiver. For radar station with two-channel on polarization the relation signal/background essentially depends on the polarizable characteristics of the target and background, i.e. on their polarizable anisotropy index. And, as it follows from received results, method of detection of the targets on is the most effective to a polarizable anisotropy index at the small relations a signal/background. If at a background of characteristic r=l, R=0, more expediently to use classical method single-channel on polarization of the target detection on a background of a earthly surface.

The Radar Targets (on a Background of Forestry Tracts) Detection Characteristics

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Variety of kinds and complexity of a structure of earthly cover largely hinder analytical determination of a scattering matrix elements and its invariant. Therefore along side with theoretical researches the important significance is acquired by experimental researches. In this connection measurements of a scattering matrix elements of earthly cover and of little dimensions the targets on their background. Comparison of efficiency of the radar targets detection on their polarizable anisotropy coefficients with a classical method of detection on a square of a module of a diagonal element of a scattering matrix was here in after conducted.

The experimental installation represented radar station two-.channel on polarization. It worked in a decimeter range of waves and was intended for serial radiation and reception of radiowave vertical and horizontal polarization. After appropriate processing in a receiving device there were modules and squares of modules of a scattering matrixes diagonal elements.

The measurements were conducted in a forestry tract, where it was necessary to conduct detection of three various types radar as a result of measurements a numerous statistical material was received, which has given a opportunity to determine the statistical characteristics of modules of a scattering matrix diagonal elements and of polarizable anisotropy degree of a deciduous forest in cases, when in this wood the mentioned above radar targets were or away.

Comparison of efficiency of detection of the of little dimensions targets on a background of a wood on a polarizable anisotropy degree and on a square of a module of a scattering matrix diagonal element has shown, that for reception of identical probability of correct detection it is necessary for the second case to increase the relationa signal/noise in limits from 4 up to 9 dB (depending on a kind of the target).

The Statistical Characteristics of Radar Target Scattering Matrix Elements

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The classification and identification of the radar target is one of the most urgent problems of remote sensing. For increase of efficiency of recognition of researched cover it is necessary to increase radar contrast of various types -of these cover. The large successes in this direction are achieved after occurrence of radiotechnical systems with polarisative processing of radar signals.

In the report new principles of construction of statistical models of a scattering matrix elements are offered.

In the basis of these principles parities, connecting scattering matrixes elements, its eigen values (λ_1, λ_2) and eigen polarizable basis coordinates (α,β) on a Poincare's sphere lies. Setting physically the justified statistical laws, describing casual character of change (λ_1,λ_2) and (α,β) can be decided a problem of determination of probabilities distribution function (PDF) of modules and arguments of a scattering matrix elements. Approximations of settlement PDF the known theoretical laws of distribution
and their check on criterion χ^2 are indicated.

It is showed, that unlike traditionally accepted for module of a scattering matrix elements of PDF approximation till the law of Relay or Gauss expediently to use *A* - distribution or Laplace's distributions accordingly.

The characteristics of a discrimination of two radar target with various a scattering matrixes are received. As a example, a wood, ploughed field, structure of urban and agricultural types, water surface are considered.

The offered method enables to construct "a generator of the radar target", giving opportunity to receive a plenty of the various statistical laws of character of change of a scattering matrix elements. The results of work are illustrated by settlement examples.

Session J11
Friday, July 17, PM 13:40-17:20
Room 450
VHF Band SAR

Organiser : L. Ulander
Chairs : L. Ulander, M. Imhoff

Improved Spatial Sampling using a Frequency Hopping Ground Penetrating Radar

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In this paper a new data acquisition strategy for a frequency hopping ground penetrating radar is described. The method uses a frequency hopping radar that transmits the higher frequencies more often than the lower frequencies as the radar moves along the survey track. By this method the Nyquist along-track sampling requirement is fulfilled at each frequency instead of at the maximum transmitted frequency only. In contradiction, an ultra wide-band radar system that transmits all frequencies at every sampling position along the survey track oversamples the lower portion of the spectrum. By optimizing the sequence of transmitted frequencies the method theoretically can reduce the number of digitized data points by a factor of two. The new sampling strategy therefore allows an increased sampling velocity, and it also gives a higher signal to noise ratio at the high frequencies that normally suffers from high attenuation in the ground medium.

The method can be extended to a two-dimensional data acquisition geometry where we use an antenna array for cross track data acquisition. Using a similar sequence of low and high frequency antenna elements along a line, the cross-track sampling requirements can be fulfilled for each transmitted frequency. By using the optimum sequence of frequencies and switching the transmitter and receiver to the relevant antenna elements, we can reduce the number of digitized data points by a maximum factor of four. The image processing algorithm sorts the acquired data points to the correct frequency and applies a wavenumber migration method to the complete data set. The method is demonstrated using both synthetic model data and real data from a ground penetrating radar.

Reference

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CARABAS Observations of Pine and Spruce Forests

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It is well known that the use of radar remote sensing to determine forest biomass is very limited at high frequencies. This limitation is due to saturation of the backscatter which occurs for very low biomasses. The problem is caused by the backscattering being dominated by small scatterers (leaves, needles and branches) at the tree tops which are not good indicators of the biomass. Longer wavelengths (lower frequencies) are sensitive to larger structures (such as tree trunks) and thus appear more promising for biomass estimation.

CARABAS is an airborne SAR system operating at 20-90 MHz. Previous results from the CARABAS I system have shown a good sensitivity to biomass for some deciduous forests. However, much of the Earth´s forest is boreal forest where pine and spruce trees dominate. This presentation describes an extension of the study of biomass dependence to these important tree types. The measurements presented are based on measurements taken with the second generation CARABAS II system from the EUFORA test-site in southern Finland. Stands of both pine and spruce of differing biomasses are investigated.

To aid in the interpretation of the results a model based on the distorted-Born approximation has been used. It has been shown previously that including coherent interactions between the different scattering mechanisms, based on ray-tracing of the scattering paths, is a reasonable first approach to modelling at these frequencies. This technique is extended here to incorporate information from a tree growth model. The extension allows a better characterisation of the forest at different ages. In addition the information on the trees' structures allows inclusion of the first-order coherent interaction between scattering from different branches.

Estimation of Forest Stem Volume Using CARABAS-II VHF SAR Data

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The CARABAS-II airborne SAR system operates in the 20-90 MHz band and uses horizontal polarization on both transmit and receive. A pair of wideband dipoles are mounted in front of the aircraft and illuminate a half-plane to either the right- or left-hand side of the flight track. Image formation is performed off-line using algorithms which compensate for the wide bandwidth and aperture angle.

Earlier studies with the CARABAS-I system have shown a high potential in estimating forest stem volume. The results concluded that the dynamic range of the backscattering coefficient among the forest stands is higher than what has been found with conventional SAR using microwave frequencies. The test site consisted exclusively of deciduous forest stands with a stem volume in the range of 0 to 210 m^3/ha.

In this paper, the ability of estimating forest stem volume in dense forests using CARABAS-II SAR data is investigated. A new test site was chosen at the forest research park Tönnersjöheden, situated in the southern part of Sweden. The forest stands consist mainly of Norway spruce (*Picea abies*) with a maximum stem volume of 1000 m^3/ha. The main reasons for choosing this test site were to study the stem volume saturation level of the CARABAS-II sensor and to investigate the accuracy of stem volume retrieval. Furthermore, the forest types are more similar to typical Swedish conditions than in earlier studies.

Boreal Forest Detection by CARABAS

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The structure of a forest is crucial for active microwave remote sensing. The longer the wavelength, the deeper down information is obtained from the forest. Therefore CARABAS has a high potential for detecting large forest structure properties and properties related to the downiest layer of the forest. Owing to the high resolution of the CARABAS images, it is possible to obtain high resolution structural information about forests.

Methods for forest information retrieval using active microwave data are studied and developed in EUFORA project. One test site for the project is Tuusula, which is situated in southern Finland. The test area contains economic boreal forest types of several kinds. The forest stands are rather small, scattered and not altogether homogeneous. The area is mainly spruce dominated and has stands of various ages. The terrain is not very hilly and surface height variation is mostly slowly undulating. However, large stones (roughly 1m diameter) are frequent in this area both on top of the surface and hidden in the topmost layer.

One CARABAS image taken in the autumn is studied. The first step in the analysis is to divide the area in forested and not forested areas. This is done using a newly developed algorithm based on the statistical properties of the backscattering. In order to detect various forest types or structures, the statistical properties of the forest structures are used as a basis for the analysis. Because the volume scattering of a forest is practically only surface scattering caused by an extremely complicated air/non-air surface, the relevant forest structure descriptor is the air distribution in the forest. Results for spruce dominated forest stands are shown.

VHF-Band SAR Image Simulations of Objects Above Ground Using FDTD

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With the recent development of ultra-wideband SAR systems operating in the VHF band, it becomes important to study low-frequency scattering from meter-sized objects. Knowledge of the scattering matrix over the frequency band and Doppler cone angles of interest can then be used to synthesize the SAR image response. Both amplitude and phase distortions contribute to the image signature of the object.

For this application we have developed a FDTD-code which is capable of computing the far-field scattering amplitude of general objects above a dielectric ground. The main advantages of using FDTD is the capability of modeling complex objects, and that results are directly obtained for a broad frequency band which reduces computational time.

In FDTD, the incident field can be created using either the total field or scattered field formulation. We use the total field formulation since it only requires source terms at a Huygen's surface surrounding the object, whereas the scattered field formulation requires source terms at every field point where material exist. The incident field within the Huygen's surface is created by sources according to the equivalence principle. Outside the Huygen's surface only the scattered field exists, which in a similar manner to the incident field, can be transformed to equivalent surface currents on a (new) surface. These currents can then be used to transform the scattered fields in the near-zone to the far-zone. In free space, the Green's function is well-known and the far-field amplitude is readily obtained in time or frequency domain. When a homogeneous dielectric ground is present, however, the transformation becomes more complicated. We solve this problem by using the reciprocity theorem. By placing a test current consisting of an electric dipole far away from the object, the Green's function can be determined, including the incident and reflected fields above the ground, or the refracted fields below the ground (Demarest *et al.*, IEEE AP-44, 1150-1157, 1996).

The far-field amplitudes from FDTD is transformed to a simulated image by using a SAR system model. The imaging geometry, data acquisition and subsequent focusing can be shown to correspond to interpolation of the far-field amplitudes from polar to Cartesian coordinates. This results in the complex image spectrum of the object which can be turned into the SAR image response by inverse 2D Fourier transformation. Appropriate corrections for range-spreading loss and antenna gain and polarization is also included.

Several different objects have been studied and will be discussed. In particular, triangular trihedrals used for system calibration purposes have been characterized in detail for different incidence angles and processing parameters.

An Airborne Low Frequency Radar Sensor for Vegetation Biomass Measurement : Initial Results from Big Thicket Forest Preserve Texas, USA

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A synthetic aperture radar sensor operating in 5 bands between 80 and 120 MHz was flown over forested areas in East Texas, USA, in an experiment to map forest biomass and detect sub-canopy soil moisture. The sensor is pulse coherent SAR flown on a small aircraft and oriented straight down. The doppler history is processed to collect data on the ground in rectangular cells of varying size over a range of incidence angles fore and aft of nadir (+45 to - 45 degrees). Sensor data consists of 5 frequency bands with 20 incidence angles per band. Sensor data for over 14 sites were collected with forest stands having biomass densities ranging from 50 to 290 tons/ha dry above ground biomass. Results are shown exploring the biomass saturation thresholds using these frequencies, the system design is explained, and preliminary attempts at data visualization using this unique sensor design are described.

Two-Dimensional Adaptive Compensation for Ionosphere Destructive Effect on Resolution of VHF Space-Borne SAR

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The advent of a spaceborne VHF SAR could give a lot of information for the remote sensing of the Earth, which can not be obtained in centimeter and decimeter band SAR's.

It is, however, known that dispersion and fluctuation phase distortions of space-borne SAR signals in the ionosphere reduce drastically the VHF SAR's ability to achieve a high resolution required to bring down the clutter which is present in case of subsurface remote sensing of the Earth.

In this paper the authors study and compare particular algorithms to simultaneously (two-dimensionally) compensate for both the dispersive phase distortions in the ionosphere that bring down the slant range resolution and the fluctuation phase distortions that reduce the azimuth resolution. The proposed algorithms for two-dimensional ionosphere distortion compensation in SAR signals have been verified experimentally by means of respective semi-natural computer processing of airborne VHF SAR real signals. Dispersive and fluctuation phase distortions were introduced in these signals, while the distortions were based on genuine data received in the course of ionosphere studies.

The radar images of various terrains obtained as a result of the processing testify to the fact that the proposed algorithms of two-dimensional adaptive compensation (with the use of auto-focusing) for ionosphere distortions of VHF SAR signals are quite effective.

Exploitation Background of the Airborne VHF SAR as Four-Frequency Radar Complex Mars Component for Sea Surface, Sea Ice and Land Monitoring

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A VHF multipolarisation air-borne SAR for subsurface sensing was designed to be used as part of the multipurpose air-borne radar system for environment sensing and ecological monitoring. Apart from the above-mentioned VHF SAR the multi-purpose radar system MARS facility also incorporates the Ka- and X-band real-aperture antenna radars and the L- band SAR. The VHF SAR parameters are tabulated below.

VHF SAR - Instrument Characteristics

Wave Length	180cm ;
Radar Type	SAR ;
Pulse Length	28μs ;
Peak Power	0,3kW ;
Radar Chirp Bandwidth	6 Mhz ;
Transmitted PRF	1000 Hz ;
Receiver Noise Figure	2dB ;
Antenna Gain	11dB ;
Antenna Beam Width :	
- vert. pl.	70° ;
- hor. pl.	35° ;
Antenna Type	PhA ;
Polarisationmode	VV,HH,VH,HV ;
Swath Width	(30-60) km ;
Incidence	20°- 85° ;
Range Resolution	(40-90) m ;
Azimuth Resolution	(50...100;10*) m ;
Data Processing	digital 1-look/multilook* ;
Total Output Data Rate	128 Kbits/sec.... 3,2 Mbits/sec *;
Radiometric Resolution	5 dB ... 0,5 dB *.

(*) - on ground data processing mode
( ) - operating mode(onboard data processing)

The VHF SAR is intended for solving a broad range of reseach and practical problems in the study and monitoring of the sea surface (in combination with Ka-, X-band SLRARs and L-SAR), sea ice and glaciers, particularly in the detection of subsurface formation of artificial and anthropogenic land origin.

The VHF SAR is featured by the synchronous sensing of the underlying surface on two polarisations. The penetration ability of a long waves band can be used to detect objects of artificial origin and the special features of a geological structure associated with available mineral resources.

As experience and calculations inicate that VV and HH polarised VHF- band allow the subsurface formations to be very effectively identified.

The paper analyses the technical features of designing the VHF-band SAR. Numerous examples are supplied of the VHF SAR practical applications in the system of the multipurpose radar system MARS facility aimed at conducting ice exploration, searching mineral resources, detecting underground works, monitoring the ecological state of water surface and serving many other purposes.

Results of Sea Surface Radar Sounding in 150 MHz Band

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In the paper, results of processing and analysis of Doppler spectrums of signals scattered by sea surface are presented. Experimental measurements were carried out at the Okhotsk radiophysical proving ground (Sakhalin Island, Aniva Gulf). The measurements data have been obtained for sounding radiation's grazing angles near to zero values.

The Doppler spectrums dependences on range and sounding direction in 105 degrees angular sector are considered. It is shown that sea surface's specific cross-section values obtained by the experimental data belong to the -45.-55 dB interval. Near sea surface wind directions estimates obtained by given Doppler spectrums have a good conformity with meteo-observation stations data. Analyzing derived dependence of Bragg spikes amplitudes difference in scattered signals' Doppler spectrums on azimuth direction of the radar sounding, the authors has made an attempt to determine form and width of angular distribution of power scattered by sea waves.

Session K09
Friday, July 17, PM 13:40-16:20
Room J
Indoor and Outdoor Propagation

Organiser : H.T. Chuah
Chairs : H.T. Chuah, M.S. Leong

Fading Statistics in The Shadowed Region of a Tree

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When radio wave propagates through vegetated areas, the received power fluctuates substantially due to scattering and absorption. This fluctuation has been shown to be influenced by density, shape, and size of the vegetation. Previous studies have shown that at 900 MHz and 1.9 GHz the scattering cross-section of a tree is dominated by its trunk and large branches. In the shadowed region of a tree, the average propagation loss in the forward-scattering direction decreases as the trunk (or branch) diameter increases. As the receiver-transmitter (or receiver-tree) distance increases, the effects of trunk/branch scattering on propagation loss become negligible, and the average level of the propagation loss approaches that of the plane-earth model predictions.This paper examines the fading statistics due to the tree trunk and tree crown in the shadowed region. Theoretical investigation of radio wave scattering mechanisms of a tree is carried out by modeling the tree trunk as a vertically oriented finite size cylinder; the branches as a collection of randomly oriented cylinder with finite sizes; and the deciduous leaves as a collection of randomly oriented thin discs. The tree crown is modeled as a collection of leaves uniformly distributed in a hemispherical shell. In this study, first order scattering due to the crown and second order scattering due to the crown-trunk interactions are considered. In the tree crown shadowed region, model predictions show that the envelope of received electric field is Rayleigh distributed. The effects of tree parameters on fading statistics in the tree crown shadowed region will be presented in this paper. Model predictions also show that the tree crown (leaves)increases the path loss by 20–30 dB.

Analysis of Radio-Wave Propagation in a Four-Layered Anisotropic Forest

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There has been considerable interest in the study of radio-wave propagation in vegetated environment. The presence of forest foliage causes great attenuation of radio waves along radio paths and reduces the communication range of the radio equipment. In planning a communication link, quantitative knowledge of the excess transmission loss suffered by the radio waves due to the presence of the foliage is essential. Most investigations have made use of a typical model which replaces the forest with a homogeneous and adopted and commonly used in the analysis of propagation mechanism in forest environment [1,2]. Two lossy dielectric layers placed over a semi-infinite ground plane are used to represent the canopy layer and trunk layer of the forest, respectively. Two methodologies, the Hertz potential method and the dyadic Green's function (DGF) technique, are usually applied in these studies of electromagnetic radiation and propagation in medium.

Dyadic Green's functions have long been proved to be a valuable tool in the representation of electromagnetic fields. Dyadic Green's functions in their vector wave eigenfunction expansion forms for anisotropic four-layered geometry were used to solve the problem of electromagnetic wave propagation in the four-layered forest model. A generalisation of the dyadic Green's functions for the case of a multi-layered medium, and expression for the coefficients of the scattered dyadic Green's functions in multi-layered medium have been recently obtained, which facilitated the analysis of electromagnetic wave propagation in semi-infinite media [3]. From these functions, the electric fields of the electromagnetic waves in the trunk and canopy layers, radiated from an inclined dipole antenna located in the trunk layer were obtained. The electric fields were subsequently evaluated using approximate methods, the saddle point technique and the branch-cut integration technique, to obtain analytical closed-form solutions of the electric fields. The analytical solutions were thereafter used in numerical simulation of pratical situations such as attenuation and trasmission loss, using dielectric constant and conductivity of typical forest. A good agreement has been found from previous works.

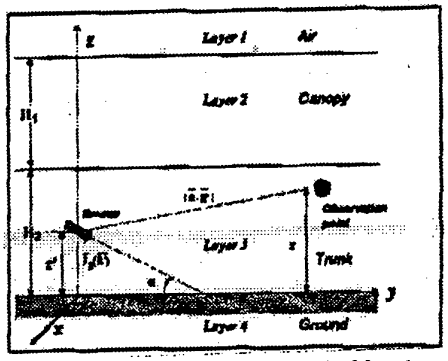

Fig. 1 Geometry for the forest model of four layers

The introduction of anistropies in the media has been under investigation. Formulation of the dyadic Green's functions, in their eigenfunction expansion forms by cylindrical vector wave functions, for planarly multilayered structures consisting of anisotropic media has been locked into, and it is found that the formulations can simplify the analysis of electromagnetic propagation in forest environment, now modelled as anisotropic medium. Detailed results will be reported during the conference PIERS'98.

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Propagation Measurements and Modelling for an Indoor Wireless Communication Systems

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In an earlier paper [1], we have formulated an improved three-dimensional ray tracing technique based on multiple-image and ray launching concepts for applications to modelling indoor wireless communication systems. The technique yields large improvements in terms of accuracy, computing efficiency and memory requirements compared with the conventional «brute-force» ray tracing method. It is more flexible than the conventional image approach in the sense that propagation environments with complex geometries can be handled with ease. The improved technique makes use of multiple-image concepts to achieve accuracy and computing efficiency, and uses the ray launching technique to account for complex propagation paths. However, this improved technique [1] neglected the effect of transmission through walls, floors, ceilings etc.

The purpose of this paper is to derive a comprehensive three-dimensional propagation model for an indoor wireless communication system. The model includes all possible propagation paths i.e. inclusive of an arbitrary number of reflections in combination with an arbitrary number of transmissions through the scatterers and obstacles as well as diffractions from corners of buildings and also subsequent reflections or transmissions from such diffracted signals. The model will be extended to include the case of a multifloored building. Furthermore, by incorporating the concept of cones of rays as in [2] for each of the images, the computation time can be further reduced by examining whether the receiver is within reach of the cone of rays of a particular image, and thus greatly reducing the number of images or rays need to be tested.

Our model is applicable to indoor, outdoor, indoor-outdoor or inter-floor propagation environment. To test the validity and applicability of our model, we have done a series of power delay profiles measurements in various office environments. Comparisons between our theoretical model and the measured power delay profiles were made on location-by-location basis for all these measurements. Path loss and RMS delay spreads were predicted with a standard deviation of 3.7 dB and 6.3 ns respectively. Comparisons of delay profiles show that many multipath components are predicted with similar time delays. The good general agreement between the model and measurements indicates that our model works well for such wireless communications applications.

References

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Radio Propagation Measurements and Modeling

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In this paper, radio propagation measurements was designed to obtain channel model parameters for the microcell multimedia communication system which is to set up on NCU campus. These include the signal attenuation and delay spread due to trees and surroundings. A DGPS-based measurement system was setup for this purpose. The statistical characteristics of measured data were analyzed. The path loss is proportional to 1/Ra where a is between 1.3 and 1.5 depending on the propagation environment. Extensive measurements of attenuation characteristics for Ficus microcarpa were performed. The averaged attenuated signal level is about 1.0 dB/m which should be regarded as large, considering the case of dense vegetation in subtropical and tropical regions. Statistical analysis indicates that the propagation loss due to tree can be best described by lognormal statistical model. Numerical simulation by means of radiative transfer confirms the measurement results. The delay spread measurements were also carried out. It is found the spread phenomenon is not so obviously at the test site. This is not surprised because the multipath effects under the experiment setup is not pronounced. The maximum delay spread measured is about 24 ns corresponding to 5 MHz coherent bandwidth.

Indoor Propagation Measurements in Various Office and Laboratory Environments

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Recently, environment-specific theoretical models have been introduced to characterise and simulate the propagation channels, and to provide basic understanding of signal propagation for improving efficiency, reliability and capacity of wireless communications systems. The advent of theoretical models has led to great demand for more published measurements with well-documented parameters, which could be used to evaluate or validate theoretical models. In this paper, delay profile measurements, using swept-frequency technique, carried out at various office and laboratory environments are discussed. Propagation parameters such as path loss, rms delay spread, etc., are derived from the delay profile measurements. In addition, office and laboratory environments are simulated using UTD propagation model with improved three-dimensional ray tracing technique. Comparisons of measured and simulated propagation parameters are investigated. These published results could also be used to validate other theoretical models, and to provide better understanding of propagation mechanism in various indoor scenes, especially those in tropical countries. This is important in the development of a practical propagation model.

Precise 3d Based on Ray Launching Application in Urban Propagation

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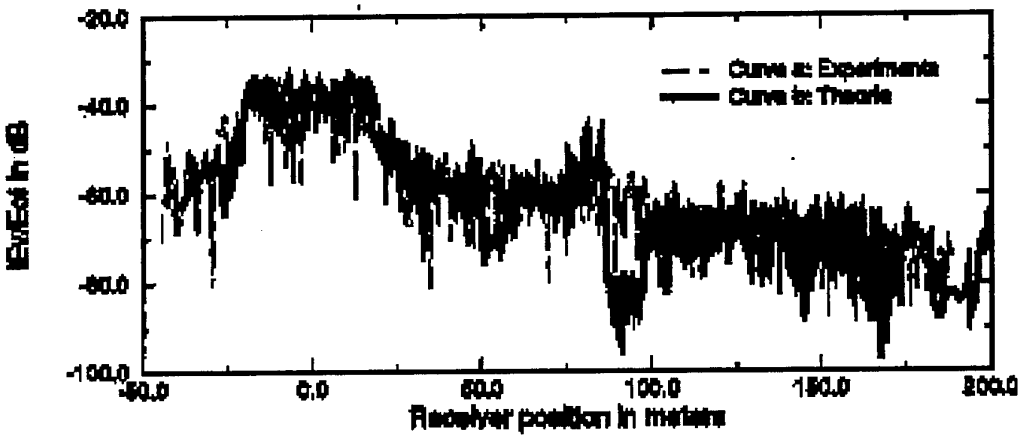
Mobile telecommunication are developing rapidly and it becomes very important to get prediction tools in order to calculate the electromagnetic field anywhere in a town, for example as a function of the position of the fixed emitting antenna. Indeed, this allows to avoid extensive measurements for choosing the optimum position and also to predict the coverage area and the channel impulse response.

This paper proposes a real 3D propagation model based on ray launching techniques associated to asymptotic methods like Geometrical Optics and Uniform Theory of Diffraction. The originality of the method is that each path between emitter and receiver is exactly determined. Indeed, the first step uses ray launching to find the successive reflecting faces met by the ray, up to the receiver. Then, the image theory allows us to determine the real path joining emitter and receiver. An analogous procedure is made to find all diffracted rays. Finally, each component of the total received field or impulse response can be calculated (direct, reflected, diffracted ,reflected then diffracted or contrary). The urban environment is modellized by a set of dielectric parallelepipeds representative of each building and characterized by its conductivity and relative permittivity.

In order to validate the proposed model, some experiments at 1 GHz have been carried out in a suburban area with many high buildings. The emitter was placed over a building top and the receiver on a van roof, the height of each antenna was 22 m and 2 m respectively. The figure below gives an example of the experiments results (curve a) compared with theoretical model (curve b). The good agreement between these two curves (the maximum difference is less than 5 dB) shows that field strenght in urban area can be predicted by the proposed model with a good approximation.

This model allows a complete study of the effect of the emitter position on the quality of a radiomobile link. Indeed, in urban area, the emitter height (relative to the buildings ones) has a great effect on the received field level and the delay profile. The analysis of the results obtained in many different configurations in canonical problems shows that simulations of the propagation in urban area can be made with a 2D model if the fixed emitting antenna is below the buildings roofs level but must use a real 3D model such as the one proposed here, if the emitter is over the roofs.



A Ray Tracing Code for Radioelectric Coverage in Urban Areas

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In the planning of a mobile communication system the determination of the coverage region of an antenna is essential if an optimal transmitting stations layout is needed. The development of computational tools able to solve this problem in a reasonably short time is therefore advisable. The geometrical dimension of the computational domains (linear dimension of the order of hundreds of meters) and the frequency of the transmitting antennas (of the order of 1 GHz) imply that a volume discretization method is not feasible due to the high number of unknowns involved. Approaches using surface discretization techniques also lead to computational times incompatible with operative requirements. A popular method for this kind of application is ray tracing. This technique can easily provide a Geometrical Optics solution and can be complemented by an evaluation of the contribution of diffraction. This work concerns the implementation of a ray tracing/diffraction code. Due to the limited knowledge of problem data (in particular neither terrain elevation data nor buildings' height are available) a two-dimensional ray tracing can be used, from which three-dimensional data can easily be derived. A widely used method for estimating diffraction is the Geometrical Theory of Diffraction. An evaluation of the diffraction effects can also be obtained by a Kirchhoff's Integral-based technique, derived by applying the stationary phase technique to the boundary wave integral. This approach is shown to be the last step (0 dimensions) of a dimensionality reduction procedure which begins with the Kirchhoff's Integral method (2 dimensions) and proceeds with the boundary wave approach (1 dimension). This technique, coupled to ray tracing, is implemented by a C++ code. Results are then compared to experimental data.

Session K10
Friday, July 17, PM 16:20-19:40
Room L
Sensors : Radar and Radiometer II
Chairs : B. Blume, F. Downs

Comparison of Monostatic and Bistatic Radar Imaging

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This study presents an inversion method for monostatic and bistatic synthetic aperture radar imaging. The method is based on a Fourier analysis (Doppler Processing) of the bistatic synthesized array's data followed by a phase modulation analysis of the doppler data. The approach incorporates the phase information of the wavefront curvature in the transmitted waves as well as the resultant echoed signals. The doppler data are shown to provide samples of the reflectivity functions spatial Fourier transform within a band that depends upon the monostatic and the bistatic angles and ranges.

The transmitting an receiving radiation patterns of a radar resemle as a spherical wave. The existing SAR inverse methods are based on approximations for spherical radiation pattern of the radar e.g., the fresnel approximation or the plane wave approximation. These methods fail in the case of high resolution imaging of a large object area. This study has inversion methods that remove these restrictions in monostatic and bistatic SAR problems.

In this study, various number of target functions, simulation images for different radar positions, and synthetic aperture lenghts are obtained for the monostatic and bistatic SAR. Obtained results are classified in terms of signal to noise ratios. When obtained results are investigated, it is seen that resolution ofimages in the bistatic case are better.

Near Sea Surface Wind Speed Determination by Combining Altimeter and Scatterometer Data

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The results of some theoretical researches and numerical estimations of a sea surface radar cross section temperature-wind dependences are presented. Spectral, angular, polarization, air and water temperatures, wave and wind features of a sea surface microwave reflective characteristics are considered.

It is shown, that even at fully developed sea wave condition and at a priori known wind direction sea surface radar cross section has unambiguity by two principal and comparable parameters: by wind speed and the difference of air and water temperatures. And this unambiguity is the main obstacle at an attempt to solve microwave inverse problem and precisely to determine near sea surface wind speed by the data of radar observations.

Analysis of performed theoretical researches and numerical estimations has shown, that near sea surface wind speed can be ambiguously determined if simultaneously to use the results of two positional radar observations. In the basise of presented theoretical resalts the principal conditions for observation are determined.

Microwave radar method and corresponding radar system developed for a near sea surface wind speed ambiguous and high precise determination are described. Suggested method and radar system allow with high precision, simultaneously to estimate and the difference of near sea surface air and water temperatures.

In this presentation will be considered the possibilities of satellite information utilization to confirme experimentally the theoretical predictions. And under favorable circumstances the results of theoretical and experimental data comparison will be presented.

Radiation of a Charged Current Stream, Moving Near Surface of Medium with Periodically Modulated Parameters

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Nowdays a great interest in investigations of radiation in inhomogeneous and nonstationary media arises again because of the wide use (vast implementation) of such media in microelectronic devices. For example, strong electromagnetic waves (laser beam), propagating in guided structure changes its dielectric properties: dielectric permittivity of a medium becomes periodically modulated in time and in space.

In this work we consider a radiation of a charged current stream, moving near surface of a medium, whose permittivity varies according to the travelling wave law :

$$\varepsilon = \varepsilon_0 + \varepsilon_1 \cos(\mathbf{k}_0 \mathbf{r} - \omega_0 t),$$

where ε_0 is the nonperturbated permittivity of medium, $\mathbf{k}_0$, ω_0 is the wave vector and frequency of medium modulation, ε_1 is a small perturbative parameter.

In the framework of a perturbation theory the problem can be reduced (exept zero order of approximation) to the solution of Maxwell equations with distributed effective current and charge in the modulated medium. In our case distributed effective charge and current are written as :

$$\rho_{eff}^{(n)} = -\frac{\varepsilon_1}{4\pi} div\left[\cos(\mathbf{k}_0 \mathbf{r} - \omega_0 t)\mathbf{E}^{(n-1)}\right], \quad \mathbf{j}_{eff}^{(n)} = \frac{\varepsilon_1}{4\pi}\frac{\partial}{\partial t}\left[\cos(\mathbf{k}_0 \mathbf{r} - \omega_0 t)\mathbf{E}^{(n-1)}\right]$$

Here **E** is the electric field strength in (n-1)-order of approximation of perturbation theory, n is the order of approximation of perturbation theory.

It is shown, that spectrum of such radiation is Doppler-like with all features of Doppler spectra in media with refraction. In n-order of approximation of perturbation theory the spectrum has the following form :

$$\omega_n = \pm \frac{n(\omega_0 - \mathbf{k}_0 \mathbf{v})}{(1 - \beta\sqrt{\varepsilon_2}\cos(\theta))},$$

where **v** is the velocity of the stream, β=v/c, ε_2 is the dielectric constant of the medium where the stream moves, θ is the angle of radiation spread, relative to the direction of the stream velocity.

For the problem under consideration expressions of spectral and angular distribution for radiation energy of a moving charged current stream have been obtained and numerical simulations for a wide range of the parameters of the stream and medium have been carried out. Moreover, the application possibility of such structure as a source of electromagnetic radiation in wide range of frequencies was studied. It has been proposed to use a system of several streams to rise the energy of radiation.

Laboratory Investigations of Temperature-Wind Features of Ruffled Water Surface Microwave Radar Cross Section are due to Temperature Dependence of Water Surface Short Wave Spectrum Characteristics

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The results of laboratory investigations of relationships between absolute values of ruffled water surface microwave radar cross section and near water surface air and water temperatures difference are caused by temperature features of a water surface short wave spectrum density are presented.

Laboratory researches of ruffled water surface radar cross section temperature-wind dependence were carried out by microwave active means of observation indoors, excluding any subsidiary air streams (winds) and any sufficient changes in environmental conditions.

To provide necessary decoupling between microwave active and passive devices utilized for these experiments two positional sensing method was applied, assuming spatial separation of microwave transmitter and receiver. The detailed description for a methodology of the performance of these experiments, that took into account angular and polarization features of ruffled water surface microwave radiative and reflective characteristics and algorithms of measured data processing are presented.

Microwave radiation of tray water surface sizes 1.5 x 0.8 x 0.08m^3 was realized by uninterrupted noise signals of X-band transmitter at central frequency 7.5GHz and banwidth ~10%. Output power of applied transmitter corresponded to 1500000K.. The reception of the signals reflected from ruffled water surface was realized by X-band radiometer receiver with bandwidth ~10% and with sensitivity <0.15K at integration time 1s. Experiments were carried out for vertical polarization of both radiated and reflected signals. Applicated horn antennas for both active and passive devices have provided practically complate illumination of tray water surface and far zone observation conditions for both transmitted and reflected signals.

Presented experimental data show, that at low wind speeds the values of the steepness of dependence between ruffled water surface radar cross section and air and water temperatures difference may reached up to 0.5-0.6dB/K. At wind speeds ~10m/s and more the values of this steepness may fall between 0.2-0.3dB/K. Performed comparisons of obtained experimental data with the results of some theoretical estimations has shown satisfactory agreement.

Detection of Helicopters by Aircrafts Overview Radars

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Possibilities of detection and tracking of slow-moving objects in the air by aircraft overview radar stations are analised in this article. The theoretical research of signal reflected from a helicopter was conducted. The structure of the signal was explored and its spectrum-temporal characteristics was determined. Echo-signal is formed from several distinctive components connected with reflections from separate elements of helicoprter's construction.

Superposition of the reflecthions from the fuselage and bushing of main rotor gives a narrow-zone signal. Its central frequency corresponds to radial velocity of helicopter's movement, but the spector of beating is determined by linear velocity of rotor hub elements. If the radial velocity's part of helicopter's movement is low the reflections in aircrafts overview radars are cut out by the regecting filter intended for suppressing the signal from the surface. So, It is difficult to use the signal for following processing.

At the moment of mirror reflection from the edgesof the blade of main rotor a short pulsed signal must appear. The frequency of repetition of the signal and frequency of blade's "flashing" are the same. Effective surface of front edge for mirror reflection depends on the helicopter's evolution by careen and tangage. Back edge's effective surface is a little less. Such signal is enough for the purpose of detection, but it does not suffice for tracking because coincidece such "flashing" with the moment of irradiating the helicopter by the radar has a probabilistic nature (as the period of "flashing" is much longer both the duration of the pulse and the time of irradiating the helicopter by the radar). And what is more, in consequence of the stroboscopical effect this signal might not achieve the radar's entry at all for a long time.

If the angle is acute when blade is viewed then reflections from blade's butt-end must be observed. That signal is poliharmonic and consist from several components (according to the number of blades). The central frequency of each signal's component depends on momentary value of radial velocity of blade's butt-end. Due to rotor's rotation the position of line of the signal's spectrum and their value change periodically. This signal can be used for the purpose of tracking. The problem is reduce to finding of a coherent signal processing's method.

There are the expiremental data of reseach signal reflected from helicopter. Their spectral-temporal characteristics and theoretical calculation are coinsidence with electro-dinamical reflection's models.

X - Band Doppler - Radar and Radiometer System

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Combined in space and in time X-band Doppler-radar-radiometer system (DRRS) is described. Developed system may simultaneosly operate in separate modes, such as in Doppler mode, scatterometer mode and radiometer mode, and allow to research regularities of relationships between the changes of radar and radiometer signals amplitudes and radar signal phase characteristics, reflected from and radiated by the observed surface.

The time diagram of Doppler-radar, scatterometer and radiometer channels operation, as well as the diagrams of control signals of some units are presented. The technical characteristics of developed DRRS are: radar pulse duration - 1mks, pulse power - 1W, receiver bandwidth is 10%, radar channel threshold sensitivity - -144dB/W and background sensitivity - -127dB/W, radiometer receiver sensitivity at integration time 1s - <0.15K. Antenna system and antenna splitting provide all kinds of polarization, for both radar (transmitted and received) and radiometer signals.

X-band Doppler-radar-radiometer detector-identifier developed on the basis of the DRRS are presented. This detector-identifier may be successfully used for detection and classification of 16 types of anomalous formations, originated on the background of observed surfaces, due to natural and artificial change of geophysical, geometrical, kinematical, bio-chemical, etc. characteristics of the environment. It sould be used for remote control of ecological conditions of various environmental objects and areas, for instance, for sustainable monitoring of hugs of tracts of forests, internal reservoirs, lakes and seas, irrigation channels, etc. This system may be successfully used and for microwave inverse problems solution, for determination of the principal physical-chemical and biological parameters of the observed surfaces.

The principal parameters of detection and classification are the mean values and the variances of backscattered radar signals frequency Doppler-shift distribution, radar cross sections and brightness temperatures of the observed surfaces. Detection and classification probabilities for this detector-identificator are obtained. These probabilities are considerably higher than those of separate radar, radiometer and combined radar-radiometer detectors.

The Secondary Processing Algorithm for Radiometer Aircraft Radiomapping System

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This paper presents the radiomapping passive aircraft system and results of investigations of the radiomap production and processing algorithm.

Radiometer measurement system is designed in the Radio-Astronomy Institute and contains two superheterodyne radiometers of 100 GHz and 39 GHz range, electro - mechanical scanner is built as a rotatable parallelepiped with the sides which reflect the antenna beams, unit of scan sector and scan velocity control, multichannel analog-digital converter which is interfaced with a computer and program package of radio display accumulation, production, processing and visualizing. Main features of the system are presented in a table.

Feature	Value
1. Operating frequency,GHz	39;100
2. Sensitivity (with 1s integration), K	0.2
3. Antenna beamwidth	5
4. Scan sector	0-120
5. Scan velocity (scan/s)	0-40

The primary radio-heat display processing algorithm is optimized for efficient selection of boundary between contrast landscape areas and processing the display in real time.

Gradient methods of processing are highly efficient from standpoint of these criteria. At the same time the efficient of gradient methods considerably decrease with small value of ratio signal/noise.

Analysis of processing result of radio-heat displays simulated on computer and obtained by the described radiomapping system on various test landscape areas with various values of ratio signal/noise offers to assume the following algorithm :

- Median filter;
- Gradient method of weighted finite differences with determination of threshold by averaging over fragment ;
- Patch filter;
- Boundary thinning.

At that the median filter uses as preliminary processing of primary display. The gradient method is principle and the patch filter and the boundary thinning are completing stages.

Subjective estimation of obtained data shows preliminary using ofthe median filter appreciably upgrades secondary display as against using only the gradient method.

The patch filter as completing stage rectifies breaks of boundary with highly efficient but at the same time appreciably extends the boundary stripe. This note results necessity for addition in the processing algorithm the boundary thinning stage.

Therefor, the measurement radiomapping system of millimeter wave band is designed by work carried out. The algorithm of low contrast extended areas boundary selection on radioheat display of landscape is chosen by software realized and tested.

On Possibility of Reduction of Mutual Influence of Cloudy Atmosphere to Problem of Radiomapping

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Withing the shortwave part of the centimeter wave range and especially withing the millimeter wave range the problem of singling out mutual influences exerted on each other by radio heat emission of the terrestrial surface and atmosphere is still actual when solving general remote sensing problems. Such a subdivision would allow to enhance the radiopicture informativity considerably at the expense of improvement of observation of low-contrast formation and objects of sounding.

In this work the values of space correlation periods as well as those of contrasting radio heat elements are surveyed as to the terrestrial surface and atmosphere. The indicated statistical characteristics have been obtained by processing the experimental data on radio heat emission. Space characteristics of the terrestrial landscape radio heat emission have been obtained during observations from a helicopter at 3 mm wave band; the data on atmosphere radiation by way of on ground observation into the zenith at 3 mm and 8 mm wave range during passages of atmospheric fronts.

Under the analysis of the results of data processing considerable differences in distribution of space correlation periods as well as that of the terrestrial surface radio heat elements of space orientation on the one part, and cloudy atmosphere on the other part, have been revealed.

The distribution of radiating peculiarities of the terrestrial landscape micro- and meso-scale formations is of a quasiisotropic character while that of cloudy atmosphere possesses, as a rule, an expressed undulatory periodical nature.

The algorithmic base for secondary processing of radiopicture directed to singling out (filtration) of atmosphere and terrestrial surface radio heat fields is supposed to lean upon those differences.

Bistatic Radar Cross Sections of Aircrafts in forWard Scattering

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A bistatic radar development's problems have been just analyzed by several authors. The bistatic radar efficiency is determined by the effective cross section of radar targets.

In the paper, data concerning the bistatic radar cross section (RCS) at scattering angles near 180 degrees are presented. These data have been measured by an interference technique when investigating a phenomenon of signals' amplitude beating which were propagating on beyond-the-horizon tropospheric paths being crossed by aircrafts [1], [2].

The RCS studies have been carried out during radiowave propagation investigatioins on 495 km transhorizon path in south part of the Okhotsk Sea. During the measurements, an aircraft, which RCS was estimated, moved across the path when its height and range relatively the receiver were known. Attracting the method described in [3], received signals' amplitude beatings were used to determine a signal value scattered by the aircraft. The RCS value has been calculated by known geometrical parameters, characteristics of the transmitter, receiving and transmitting antennas, using the radar equation.

The measurements have been carried out for TU-134, R-3 "Orion", IL-14, IL-18, AN-26 types of aircrafts in 160, 850, 3000 MHz bands. The bistatic radar cross section estimates obtained belong to 45-80 dB (with respect to 1 square meter) interval depending on aircraft type and transmitted signal frequency. Moreover, estimates for main lobe width of these radar targets' scattering indicatrix are given.

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Beyond the Horizon Target Detection by Bistatic Radar

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Using bistatic radars opens additional opportunities, one of which is detection of targets beyond the horizon. Studying the many years experiments' data showed that such systems detected targets crossing the path at ranges from 100 to 1100 km in frequency band from 50 MHz to 6 GHz when the transmitter and the receiver were located at both ends of the path. If the target approaches the path there is observed the sharp signal splash 20 dB above the level of the scattered tropospheric signal. Detection of targets in such cases relys on the waves scattered forward by the target moving near the path. According to the Babinet principle, scattering of the waves at the angle of 180 degrees is very effective and is practically independent on the target technology of production and the quality of its surface. When the target is near the path there are observed characteristic fast signal fluctuations depending on Doppler frequency shift due to scattering by the target and on interferention of the incident and scattered signals. This fenomenon can be used in order to detect the flying object and to measure some of its coordinates or direction of movement.

There are zones of shadow on long bistatic paths using tropospheric scattering. There were not carried out measurements in these zones of shadow before, but data concerning the minimum hight of detection of targets for such paths. Wave propagation condition changes greatly along paths and it changes the level of the natural signal background (scattering, diffraction, ducts and so on) and therefore changes the ratio of signal caused by the target scattering to background. The level of the background could be higher than the signal and mask it.

In the paper there are given results of experiments on characteristics of flying targets' detection by bistatic radars along marine paths 500 km in frequency bands 10 cm, 35 cm and 180 cm. The transmitted and received signals were synchronized on the base of rubidium standard of time and frequency. There was real-time signal treatment. During the experiments there was used flying test-laboratory. According to the programme the aircraft laboratory crossed the path 14 times with the gap of 25 km along the path. The hight of the aircraft was 1000 m, 2000 m and 5000 m. Results of measurements proved the possibility to detect targets in the zone of shadow - beyond-the-horizon. There was suggested the method of the test aircraft flights with a retransmitter on board in order to fasten the estimation of expected probability of detection. This method allows to get the detection characteristics at one flight.

Authors investigate a physical statistical model of beyond-the-horizon radio line, give numerical estimates of detection characteristics in the zone of shadow. There were made several examples of bistatic radars detection zones calculations in meter and cantimeter bands. The calculations proved the possibility to low the lowest level of detection in the middle part of the path and near the receiver or transmitter. There was used the method of the successive step solution of the wave field parabolic equation in order to calculate the detection zones.

Session L09
Friday, July 17, PM 13:40-16:40
Room R01
Electromagnetic Compatibility and Interference Problems

Organiser : S. Lindenmeier
Chairs : S. Lindenmeier, R. de Leo

Simulation of Anechoic Chambers Using Transmission-Line Modelling (TLM)

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The performance of anechoic chambers can be analysed in the time-domain using transmission-line modelling (TLM). This paper presents a study of a particular anechoic chamber, fully lined with wood-backed ferrite tile electromagnetic absorber. The design of the absorbing boundary filter for the modelling of this type of absorber is presented. Finally the modelled and measured performance of the chamber are compared. The results indicate that TLM s a useful tool for chamber design and characterization.

Because TLM is a time-domain method, by using an impulse excitation and the discrete Fourier transform it is possible to obtain multiple frequency information from a single simulation. The typical bandwidth of interest for Electromagnetic Compatibility (EMC) testing is 30-1000MHz. Thus to accurately model an anechoic chamber, the frequency dependence of the absorber must be described over this range. Unlike FDTD, TLM uses travelling voltage pulses on a matrix of transmission lines and, as originally developed by Dawson to model a thin absorber, it is a simple matter to include a digital filter at the grid boundary to directly model the frequency dependent reflection coefficient.

During the presentation a range of material models and screened room simulations will be shown together with comparisons with measurements.

Integrated Solution for Modelling of Multiconductors in TLM

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The transmission-line matrix (TLM) modelling method has been long established as an elegant time-domain technique for studying electromagnetic field problems. To allow studying of field-to-wire coupling as an integral part of the TLM time-stepping process, different extensions to the basic TLM were developed, such as short-circuit nodes, short-circuited link lines, wire interfaces and wire nodes. Using wire nodes it is possible to model thin wires with a diameter much smaller than the TLM cell size and with a greater accuracy than using short-circuiting methods, but they are not devised to stimulate coupling with multiconductor systems.

Hitherto, the only available technique for incorporating multiconductors in TLM was to use so-called separated solution. In this method, multiconductors are treated separately from the rest of problem, allowing for field coupling to the wires by intoducting equivalent sources derived from knowledge of the incident field. Although this method is simple, it involves several key assumptions, e.g. any electromagnetic interaction of the wires with the rest of the structure is assumed to be negligible.

In this paper, we present, for the first time, a fully integrated solution for modelling of multiconductors in TLM by means of special multiconductors nodes (Fig. 1). The n conductors of the cable are modelled as enclosed in a fictive cylindrical sheath, used to accound for the distributed capacitance and inductance already modelled by the TLM link lines. The n conductors and sheath taken together form an $n + 1$ conductor transmission line coupled to the external environment at the centre of each TLM cell vy a break in the sheath. A multiconductor short-circuit stub is also included in the line at the centre of the model (not shown in the figure) which allows the overall capacitance and inductance of the line to be adjusted independently, while still maintaining time synchronism of the TLM pulses.

In the full paper, the complete algorithm and the results obtaines will be presented.

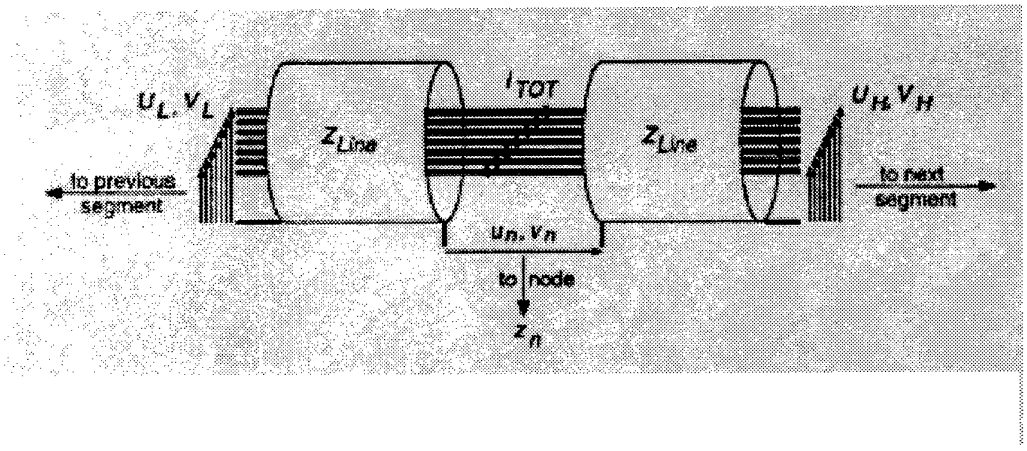

Figure 1 : Model of segment of multi-conductor in a single TLM cell

Analysis of ESD Suppressor Effects in Multilayer PCB

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Electrostatic discharges (ESD) are strong sources of reversible or permanent damages in modern electronic equipments, and to prevent their dangerous effects a first level protection consists of properly grounded metallic shields, that avoid a direct injection of an ESD current into the internal circuits; on the other hand, as a second level protection, the most susceptible PCBs are protected by suppressor devices. In this contribution a critical analysis of three different kinds of ESD suppressors is presented: the effects and the behaviour of the devices is investigated both theoretically, by means of the method developed by Winklestein, Steer, Pomerlan, for non-linear elements, and experimentally, carrying out measurements by a vectorial network analyzer and by a 1 GHz bandwidth oscilloscope.

The analyzed structure is a PCB with a ground plane and two dielectric layers: a bundle of three parallel microstrip lines is embedded into the substrate and a second bundle of three parallel microstrip lines, orthogonal to the previous one, is printed in the interface air-dielectric. The suppressor device is mounted between the central line of the embedded bundle and the ground plane; three suppressors have been considered: a diode, a thyristor, and a hybrid arrester. Since the last device exhibits three pins, it was used to protect both the central and an adjacent line of the embedded bundle, and connecting the central pin to the ground plane, in order to achieve both a differential mode and a common mode protection. To evaluate the effect of the devices a 6 kV ESD was applied at the input of the protected line, the other ports being terminated on matched loads (50 W). The response of the circuit was measured at the output of the protected line, to evaluate the limiting effect of the devices, at the output of the crossing line, and at the output of the parallel line. We have observed that the hybrid is the most effective suppressor, reducing the ESD pulse at about 200 V; however, this residual pulse propagates along the line and couples to the crossing and to the parallel adjacent line, generating a disturbance of about one order of magnitude lower than the original signal.

An important drawback of the hybrid is its simultaneous protection of two adjacent lines, which enhances the crosstalk between them with respect to the case where the device is absent: this is produced by the stray capacitance of each branch of the device with respect to ground and the unavoidable, even if small, inductance of the central pin ground connection.

The loading effect of the suppressor on digital signals, travelling along the line, has been also considered, simulating and measuring the combined effect of the device capacitance and the connection inductance.

It is noticeable that high speed digital signal ($\approx$1.5 ns rise time) are strongly affected by the insertion of the device ($\approx$10 ns rise time of the distorted pulse). Our analysis has shown that it does not exist a device suitable for whatever application, but designers have to choice the proper suppressor from time to time, taking also into account their effect on line signals.

Hybrid Mom Techniques for the Analysis and Optimisation of Hndset Antennas Radiating Close to the Human Body

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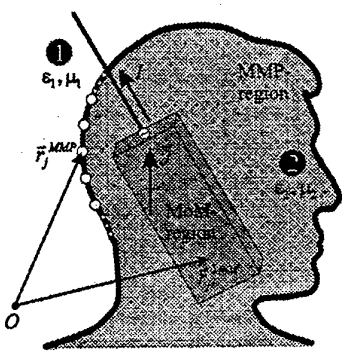
With a rapidly growing market for mobile communication sets and the public concern about possible halth risks, the analysis of commercial mobile telephones and the optimisation of antenna concepts becomes a must. An accurate and fast calculation tool with moderate main memory requirements is needed.



Conventional calculation methods like FDTD and FIT suffer from an often enormous calculation time, the application of the MoM, which is particularly suited to radiation problems, calls for rapidly in creasing main memory with increasing frequency (the human head represents an electrically large scatterer). With the MMP technique, difficulties occur when modelling bodies with sharp edges such as e. g. a complex case structure of the mobile set.

For solving such electromagnetic radiation and scattering problems, **hybrid techniques** combining the advantages of the simple methods allow the investigation of very complex structures and yield good results with small computation time and moderate main memory requirements.

One possibility is to apply the MoM with the use of a specific Green's function (**MoM-GRF**) :

$$\left.\begin{matrix}\vec{E}_s(\vec{r})\\ \vec{H}_s(\vec{r})\end{matrix}\right\} = \iint_{A'} \vec{J}(\vec{r}')\cdot\overline{\overline{G}}_{E,H}(\vec{r},\vec{r}')dA' + \int_{L'} I(\vec{r}')\hat{\ell}'\cdot\overline{\overline{G}}_{E,H}(\vec{r},\vec{r}')dL'$$

To calculate the scattered electric and magnetic fields $\vec{E}_s$ and $\vec{H}_s$, the current density $\vec{J}$ on the metallic surfaces and the current flow I along the wires has to be weighted by a specific dyadic Green's function (DGF) $\overline{\overline{G}}_{E,H}$, which takes the influence of the human body into account. Hence, no discretisation of the dielectric body is necessary (as is true with conventional MoM when applying the surface- or volume -Equivalence principle), but unfortunately the geomatry is restricted to « canonical ones » (e. g. a sphere, a layeres sphere, a spheroid or a layered spheroid) when deriving the DGF analytically, with this method very small main memory requirements and also moderate calculation time can be achieved.

A second efficient hybrid calculation method combines the MoM with the MMP technique (**MoM-MMP**). Metallic structures are treated by the MoM, while dielectric bodies are taken into account by means of the MMP (see Figure above). An iterative coupling scheme is applied, taking the scattered field of the one method as a corrective term to the other. This requires only small changes to the conventional MoM and MMP formulations, hence it is very attractive for the combination of already existing codes. In comparison ro MoM-GRF, much more complex dielectric bodies can be investigated with less calculation time and moderate main memeory requirements.

Detailed information about aspects of the theory and its implentation, the pros and cons of the single methods as well as calculation examples will be given at the time of the conference.

Prediction of RF Field-Induced Interference Voltages at Implanted Cardiac Pacemakers

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The effect of external electromagnetic fields on medical implants is often declared to be a topic of human exposure to EM fields such as the occurence of an SAR-distribution in a man's head when using a GSM phone.

However, the malfunction of an active implant, like a cardiac pacemaker, must be regarded as a classical EMI problem, because an electronic device, which is embedded in a lossy dielectric housing, the human body, is disturbed by field-induced currents on a transmission line, the pacemaker electrode.

All direct accesses to investigate the sensitivity of implanted pacemakers published so far, e. g. exposing a volunteer to a field of known spatial distribution and raising the field strength until the pacemaker leaves its regular operating mode, suffer from at least three drawbacks :

- the possible hazard of the test persons,
- the use of only few accidentally implanted pacemaker models and
- the limitation to simple field configurations.

Another concept - combining a practical (see 1.) and a theoretical (see 2.) work package - promises the achievement of more representative results with regard to the identification of dangerous situations; it is also reflected by the present development of the standardization process in this area :

1. Each pacemaker must fulfill defined interference immunity limits depending on frequency and modulation of the voltage at its input. Respective test procedures applicable to non-implanted pacemakers are standardized and threshold values for the input voltage are known.

2. The prediction of the actual interference voltage at the input of an implanted pacemaker whose owner is exposed to an electromagnetic field is a more difficult task involving reliable methods to characterize the field, to determine the field distribution inside the human body and to calculate the induced currents on the pacemaker electrode and thereby the searched voltage. It requires computer models of the body and of representative pacemakers. These models as well as the applied numerical methods depend on the frequency region under consideration. The aim of such a procedure should not only be the treatment of single exposure scenarios (e. g. special source configurations, whose amount extends to infinity), but the provision of a more universal method being able to consider a wide variety of field distributions in order to select the worst case exposure.

Two concepts of determining the maximum expected interference voltages at implanted pacemakers due to rf fields shall be presented for the important frequency regions 30 kHz - 50 MHz ("industry frequencies") and 935 - 960 MHz ("GSM downlink frequencies"). Both require completely different field descriptions and unequally detailed models of the human body. The common characteristic of the methods is a field-based modular concept allowing the synthesis of an actual field by basis elements.

For the "industry frequencies" these components consist of Taylor series terms leading to a very universal but rather complex framework whose simplification for an application in industrial practice will be discussed in detail. The field elements for the "GSM downlink frequencies" were chosen as uniform plane wave fields of different polarizations and directions of incidence in order to simulate far-field conditions around a basis station.

Efficient Modeling of Inductive Coupling with the PPS-FD-Solver for EMC-Problems

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Inductive and Capacitive coupling in many EMC problems can be described by only considering the quasi-static fields around conducting structures. Because of the very high variety of the given structures numerical methods for the fast estimation of the coupling of nearly arbitrary structures are highly demanded.

With the PPS-FD-solver the numerical computation of the field in lossless passive structures is done by using an highly efficient field analysis for the quasi-static magnetic field. The PPS-FD-solver is based on the introduction of potential partitioning surfaces (PPS) into the given structure, connecting each conductor in the structure with the outer boundary in a way that each integration path around the conducting material crosses this potential partitioning surface. Fulfilling this requirement the choice of the exact position of the PPS is arbitrary. Assuming the case of a lossless three-dimensional structure, the consideration of the field is reduced to the spatial region around the conducting material. This region is cut by the PPS so that the resulting subregion is bordered by two more surfaces which are both sides of the partitioning surface. In this new defined domain the magnetic field is irrotational and hence it can be described by a scalar magnetic potential M, in analogy to the electro-static field.

The PPS-FD-solver is applicated for the efficient and economical estimation of the field in typical EMC-problems. For this purpose we considered the susceptibility of car antennas caused by the current spikes of the ignition process. The current of the ignition process generates a magnetic field which leads to an interfering coupling to the car antenna. The receiving of car antennas is interfered then by the share of the spectrum of the current spike, which hits the receiving frequencies. After simulating the magnetic field, around the car-structure the results are compared to measured results. The table shows different calculated field values in comparison to measurement results at several locations in and around the car. The simulation is done by discretizing the space around the car (5m×4.5m×6m) into 90×68×101 elementary cells. The CPU time takes about 1h at a DEC alpha Workstation, the storage requirement is 40M. The fields are normalized by the field maximum at the cable. At the top and the side of the windscreen a local maximum of the magnetic field occurs which leads to an interference to an antenna, placed on that windscreen.

Location	Simulation	Measurement
(Ref.:) At the cable (in the bonnet)	0 dB	0 dB
5cm next to the car battery (to the side of the car)	-13 dB	-14 dB
wind-screen (top)	-43 dB	-49 dB
wind-screen (side)	-47 dB	-52 dB
0,8m above the front wheel	-66 dB	-68 dB

Analysis of the E.M. Interferences of Metallic Enclosures by the Hybrid TLMIE Method

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Metallic enclosures with apertures are widely used in many electromagnetic applications such as antennas or for shielding general electronic equipments. When these metallic enclosures are placed in the same environment, they interfere each other because of their radiating characteristics. For example, a radiating slot antenna produces induced currents on the metallic shielding of an electronic equipment. This, in turns, is a source of a back-scattered field to the antenna with the higher order scattering. This physical interaction is stronger and can produce damages when we have to deal with impulsive fields related to transient phenomena, in the time domain. These EMC and EMI problems demonstrate the importance of an accurate prediction of the electromagnetic near field, surrounding the objects and of the far field [1,2]. The numerical simlulation of the problem is highly complicated because, as happens in all the EMC problems, it is difficult to analyze with the same accuracy the near field and the far field at the same time. Using space discretizing methods like the powerful numerical methods as the Transmission Line Matrix (TLM) method [3], or the FDTD methods, the near field can be modeled for structures of nearly arbitrary geometry. For the field analysis of structures with infinitesimal thin metalization planes, apertures of simple shape and simple dielectric layers the integral equation (I.E.) method related to the method of moments (MoM) approach is a powerful and efficient tool [4]. But, when the complexity of the geometry and of the shapes increases, the above method present highly analytical and computational difficulties.

In recent contributions [5], we presented a novel hybrid Transmission Line Matrix-Integral Equation (TLMIE) method, combining the advantages of the TLM method and the advantages of the I.E. method.The TLM method is very flexible for modeling general structures with arbitrary shape while the Integral Equation method allow us to incorporate the treatment of large free space regions. The general purpose of such a method is to realize an accurate prediction of the e.m. field in a general EMC situation.

In this contribution we apply the TLMIE method for the analysis of the e.m. coupling and interference between two metallic enclosures, embedded in the free space region.

The entire space is subdivided in three regions: two closed regions and an open region. The closed regions are constituted by physical or imaginary surfaces of interface surrounding the metallic enclosures. The open region is the free space region. Inside the closed region the field is evaluated by the TLM algorithm. At the surfaces of interface the electromagnetic field is expanded in subdomain base functions. The expanded fields on the interfaces are then related to each other by the Green's functions in the time domain. By using the continuity of the fields we provide the appropriate EFIE and MFIE integral equations for the total tangential field. These integral equations are then discretized following the method of moments approach. We derive a matrix system whose solution provides the unknown expanding coefficients of the e.m. tangential field. After that we have an accurate and rigorous description both for the near field, by the TLM and for the far field by the the Green's functions in the time domain.

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The TLM-Integral Equation (TLMIE) Method for Solving Radiation Problems in Planar Waveguides

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Planar transmission waveguides are widely used in microwave, millimiter-wave circuits and high-speed digital circuits. These are, for example, striplines, microstrips and coplanar waveguides. They are used as normal transmission lines or they represent feeding lines for planar antenna structures. In the latter case they are efficient antennas, like the microstrip antennas. But, due to their physical characteristics, they can be sources and receivers of electromagnetic interferences with respect to other devices placed in the same enviornment. This is the case, for example, of the e.m. coupling between a microstrip line and an impinging field coming from another antenna. In this case it is necessary to analyze and predict the e.m. coupling between the intereferent field and the microstrip, in order to design an appropriate shielding. The analysis of the susceptibility of the structure is particularly important in the time domain, with transient phenomena in response to an impulse excitation. The presence of these impulsive fields provides a great amount of e.m. disturbance against wich an equipment should be immune. In this contribution we analyze the e.m. interference and coupling between a dipole antenna and a microstrip integrated circuit, by means of the Transmission Line Matrix-Integral Equation (TLMIE) method. The TLMIE method has been proven to be a powerful tool for solving EMC, EMI and general radiating problems [1,2].

The reason for the combination of both methods is, that the TLM method is very flexible for the modeling of general structures with arbitrary shape [3], whereas the integral equation (I.E.) method allows to incorporate the treatment of large free space regions. In the TLMIE method the space of the entire problem is subdivided into subregions to which the different methods are applied. By this way the modeling of complex structures is simplified by segmentation. At the boundary interfaces of these subregions the transverse e.m. field is expanded by means of subdomain basis functions. The expanded fields on the interfaces are then related to each other by Green's functions. By using the continuity of the fields and taking into account the orthonormal properties of the expanding functions, we derive a matrix system whose solution provides the unknown expanding coefficients of the e.m. field. The efficency of the TLMIE method has been already demonstrated by studying a typical EMC problem regarding the radiation from a rectangular aperture in a shielded metallic box [1], [2].

For the analysis of many radiation problems the Method of Moments (MoM) is a common tool [4], but its efficiency is related to the geometry of the given structure. Especially in the case of different combined dielectric-metallic structures, the Method of Moments presents increasing analytical and computational problems. On the other hand, the TLMIE Method is applicable very easily to a large variety of problems for structures of nearly arbitrary shape and in large free space enviornment.

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Session M09
Friday, July 17, PM 13:40-17:00
Room R03
Short Range Microwave Applications

Organisers : Y. Leroy, A. Mamouni
Chairs : A. Mamouni, F. Bardati

RECENT INVESTIGATIONS OF THE NEAR-FIELD ZONES OF WAVEGUIDE TYPE ANTENNAS

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Antenna systems operating at ultra-high and microwave frequencies are used to couple electromagnetic power into body tissues for hyperthermia induction, and to couple thermal noise power from tissues for radiometric temperature measurement. For both types of application, the antenna must be placed in contact with body tissues or similar material if the coupling is to be efficient. The pattern of power deposition produced by an antenna must be known if proper, safe tissue heating is to be achieved in hyperthermia treatment. Similarly, the antenna spatial response must be known if measured radiometric temperatures are to be related to actual tissue temperatures. Both of these patterns depend on the antenna properties and on the tissue dielectric properties. Over the range of frequencies of interest here, the power attenuation length in the tissue is similar to an antenna aperture dimension and the important features of an antenna response lie in its near-field zone.

The antenna fields have been modelled using both modal analysis [1] and the matching of the transverse electric and magnetic fields at the aperture. The antennas studied form rectangular and circular cross-section dielectric loaded waveguides. These operate in the dominant waveguide propagation mode, but the aperture discontinuity excites higher-order modes and these have been found to significantly affect antenna performance. The modelling has been applied to homogeneous and stratified tissue media. The development of microwave radiometry in the industrial domain where materials can be greatly non-homogeneous impose to use a numerical computation of the electromagnetic field [2]. We compare also the results obtain with this type of software in the near field zone.

The measurements presented have been made using the non-resonant field perturbation technique in which a small dielectric or conducting body is moved through the field of a test antenna which is radiating into a volume of tissue simulating material [3]. The presence of the perturbing body changes the stored energy and dissipation in the field, which can be measured as changes in the reflection coefficient of the antenna and directly related to the power density in the field.

Comparisons have been made of the computed and measured power density fields produced by rectangular and circular aperture antennas when coupled to different types of tissue simulating materials. The results confirm the excitation of higher order modes at the aperture and show the general forms of field variation expected for change of frequency or change of dielectric properties.

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An antenna design for near-field non-contacting microwave radiometry

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Multi-frequency radiometry is based on spectral measurement of the temperature-dependent electromagnetic field irradiated by a lossy body in the microwave frequency range. Temperature retrievals can be obtained by treatment of radiometric data measured externally to the body.

A major source of system errors or even impracticability of microwave radiometry for temperature measurement is the receiving antenna. We propose a cylindrical dual-reflector antenna as a possible non-contacting device to collect thermal radiation. The system includes a TEM pyramidal horn, two reflectors and a layered lossy cylinder simulating a human body. The reflector synthesis was performed by a geometrical optics method based on power conservation inside ray-tubes and optical-path length conservation. Due to reciprocity in antenna theory, the optimal reception problem for the thermal radiation of a small deep-seated volume within the cylinder is that of focusing antenna radiation to that volume. The focusing problem has been solved by determining the complex coefficients of a series expansion of the electric field on a plane in front of the cylinder. The electromagnetic field, radiated by an antenna synthetised according to the above method, has been calculated by means of the FDTD method and the results agree with the theory.

Thermal Conductivity and Thermal Emission Inverse Problems

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Methods of subsurface radiometry monitoring of the temperature and heat flux dynamics are presented. They are based on simultaneous solution of equations of radiation transfer and thermal conductivity [1,2].
The expressions connecting the temperature distribution and heat flux dynamics with the brightness temperature of its thermal radio emission are obtained for half-space and for space outside of sphere. The approach developed is used for non invasive radiometry investigations using measurements at wavelengths 0.5, 0.8, 3, 9 and 13 cm.

On the base of radio brightness dynamics measurements of soils the subsurface temperature profile and heat flux evolution has been retrieved.

The investigation of heat and mass exchange through the air-water interface have been carried out both in laboratory and natural conditions.
Using the laboratory measurements of evolution of water radio brightness at wavelength 0,5 cm in the process of air turbulization (using fan) the dynamics of temperature profile in the water and in the air viscosity sublayer as well as the evaporation rate through water-air interface have been determined. The viscosity sublayer depth in this process has been also determined from measurements data (about 0.2 cm). The strong dependence of radio brightness dynamics on water turbulization gave a simple method to estimate the depth of water cold thermal film.

The investigations of thermal film formation and heat flux variations related with the wind variations in natural conditions (in open water pool) have been carried out using measurements of radio brightness dynamics at wavelength 0.5 cm.

Thermal history inverse problems are also discussed. The solution of the new inverse problem for retrieval the temperature profile evolution of half-space by thermal emission dynamics including time interval in the past before measurements is presented.

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A New Algorithm for Microwave Radiometric Temperature Profile Retrieval

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This work is concerned with a feasibility study of an application of multifrequency microwave radiometry to the non-invasive measurement of deep brain temperature in new-born infants. According to our present design, a dielectric-filled waveguide antenna with a 2cm-by-3cm aperture will be used to cover the entire frequency range of measurement from 1GHz to 4GHz. The aperture size is fairly large compared to the normal size of baby heads, which we consider is ellipsoidal with a bi-parietal (ear-ear) diameter of 8cm and a 10cm occipito frontal diameter.

In this particular application, we assume that the temperature varies with the distance from the head surface, z, only. Then, the 3-dimensional radiometric weighting function for the antenna-head structure is integrated over the ellipsoidal shell at a constant temperature to obtain a 1-dimensional weighting function, which may be written as $W_i(z)$ for a measurement frequency band centered at f_i. The radiometric signal can be written as, $T_{B,i} = \int_{avf} W_i(z)T(z)dz$ (avf : antenna view field), where $T(z)$ is the temperature profile to be retrieved from the multifrequency radiometric data.

To represent the gross feature of unknown temperature profile, we introduce a temperature profile model function,

$$T(z) = T_0 + \Delta T\{ \exp(-z/a) - \exp(-z/b) \},$$

where the model parameters ΔT, a, b are determined by fitting $T_{B,i}$ to the radiometric data. Furthermore, we assume that the temperature distribution takes a maximum at the center of head. As a consequence of this assumption, a and b are no longer independent; i.e., either a or b is need to be determined from the radiometric data. The reduction in the number of the unknown parameters is effective to improve the resolution of the temperature estimation by this technique.

Caracterisation of Breast Tumors by Microwave Radiometric Imaging

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Near-field microwave radiometry is capable of detecting 'hot spots' in dissipative media by the measurement of natural excess noise signal emitted by these 'hot spots'. A new challenge is to characterise them. The radiométric measurement is a convolution between the weighting functions [1 - 2] and the physical temperature inside the body. So, the definition of the absolute weighting functions and a suitable inverse process by deconvolution allow to quantify this physical temperature.

The main medical application is the characterisation of breast tumors [3]. The MicroWave radiometric Imaging (M.W.I.) is a non-invasive technique and a totally harmless procedure for the patient because no waves are emitted. We have begun a new campaign of measurement at the hospital on patients. The medical exam consists in realising two radiometric images. The first on the healthy side and the second on the pathological side in order to make a comparison between the two sides. We work specifically on small and non-palpable lesions to characterise them in terms of benignity or malignancy in comparison with the others existing techniques. For the conference, we are going to establish the state of results obtained after one year of measurements (one hundred patients) in terms of specificity, sensibility, predicted positive and negative values of this method. If the diagnostic capability of this method is confirmed, the M.W.I. will permit a less traumatic and faster characterisation of tumors than some actual diagnostic methods.

We have seen that a deconvolution process can be applied on radiometric images for the case of small thermal volumes in water. We try now to apply this process on clinical images. We use several inverse processes, among others, deconvolution and Wiener filtering [4] or deconvolution under strain and Deriche filtering [5]. We are going to conclude on the supply for the improvement of quality of diagnosis.

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A Two Dimensional Thermal Microsensor Based On Microwave Correlation Radiometry

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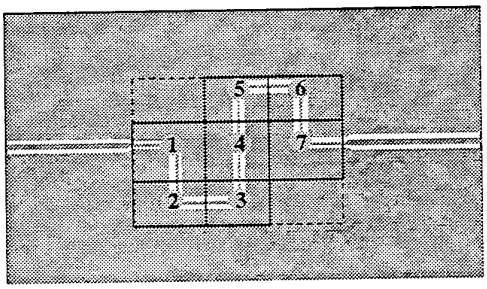
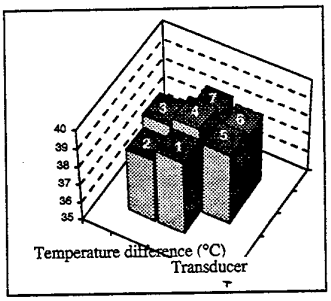
Previous studies have suggested the possibility of a non-contact thermometry in a lossy material [1] or along a lossy passive transmission line, by means of microwave correlation radiometry [2][3]. In this process, the passive two port is first connected to the inputs of a microwave correlator and provides electromagnetic thermal noise signals which exhibit some correlation if adequate conditions are fulfilled. Then the output signal recorded versus the delay time of the correlator gives the correlation function of the two noise signals. Provided we have the knowledge of the radiometric weighting functions of the different subvolumes of the two port, i.e. parameters which describe the coupling of the subvolumes to the radiometer, it is possible to retrieve the temperature profile in the material through the application of a convenient inversion process. In this aim, Kalman filtering has already been shown to be efficient.

This principle has been applied in the conception of a two dimensional thermal sensor achieved as follows. The sensor, or transducer, is a lossy coplanar transmission line deposited on an alumina substrate ; its central ribbon (0,05 µm titanium and 0,1 µm gold) exhibits an amount of resistive losses compatible with the process. The weighting functions are determined by the computation of scattering parameters of each element of the line with M.D.S and verified by a global measurement of the two port. A Kalman filtering is applied to the radiometric data measured as a function of the delay time with a radiometer of central frequency 3 GHz and bandwidth 2 GHz.

When the shape of the transducer is a meander, we can achieve a two dimensional temperature retrieval and get seven thermometric data on an area 10*6,5 square millimeters. In the oral presentation of his work, we will also explain how to proceed in order to decrease the size of the sensor.



Geometry of the meandered line



An example of temperature profiling

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Short Range High Data Rate 60 GHz Spread Spectrum Wireless Communication System

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Today's telecommunication networks are passing through a rapid evolution as a result of the ever continuing advances in enabling technologies and the new demands on telecommunication services. This evolution is characterized by two major trends : higher mobility to increase the network flexibility and higher data rates to include maximum of services. The proposed system will combine these two aspects. It would be, as far as we are concerned, the first wireless system working at about 60 GHz, which provides a dozen of virtual channels of 10 Mbits/s each modulated by direct sequence spread spectrum (DSSS).

The system is set up around three physical channels of 200 MHz bandwith, distributed in the 57.2-58.2 GHz band. Each physical channel contains potentially four completely independent channels of 10 Mbits/s. They cohabit together thanks to an asynchronous direct sequence code division multiple access technique (DS-CDMA). Without any synchronization condition, we plan to supply a total capacity of (4x3)x10Mbits/s. Let us focus our attention on the two main parts of the system : the radio front head and the baseband processing circuit.

The millimeter part of the front end is a set of monolithic microwave integrated circuits (MMIC), which have been designed by LETI with the collaboration of IEMN. Low noise amplifiers, power amplifiers and up-down converters have been processed on a 0.2 µm AlGaAs/InGaAs/GaAs pseudomorphic HEMT technology. As an example, we give in figure 1 the design of the low noise amplifier, which has a gain greater than 17dB and a noise factor smaller than 5dB in the 57.2-58.2 GHz band.

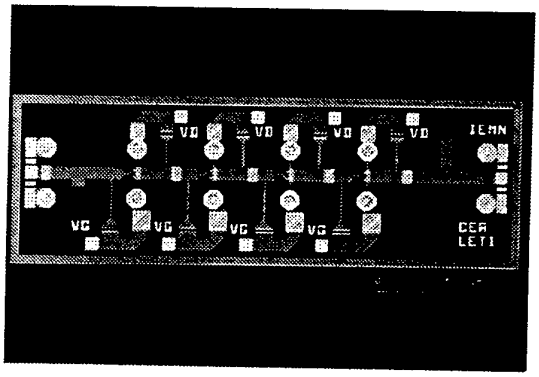

Figure 1: Low Noise Amplifier

The second challenging point of the system is the baseband signal processing module. The DSSS modulation brings the system a great discretion due to its low power spectral density, a bigger immunity against narrow bandwith spurious signals and an excellent behaviour in multiple path environnement with an adequate receiver architecture. But in fact, in order to recover the data from a DS-CDMA signal, a set of operations have to be worked out: matched filtering, delaying, demodulation, clock recovery and multi-user detection as a minimum. These functions have to be processed at a speed which depends on the length of the spreading sequence, on the modulation scheme and, obviously, on the data rate. In our case, a data rate of 10 Mbits/s, a 31-long spreading sequence and a DQPSK modulation lead us to a processing speed of 155 MHz. Thanks to progress in microelectronics, it is now possible to develop a powerful application specific integrated circuit (ASIC) to carry out the required functions. This future ASIC will also include a diversity function and a channel estimation to improve the data decoding.

The planned applications of this system are numerous. As soon as the dual need of high data rates and relative mobility is present, the system would be a great solution. For example, it could be used for the simultaneous transmission of video from a dozen of vehicules in a factory to a control office, or in a wireless local area network (WLAN).

New telemetric and positioning sensors by microwave interferometry.

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The ability of microwaves to propagate easily in a hostile environment even if perturbed by water vapour, fog, clouds, rain, snow, smoke or dust can lead to several kinds of applications, i.e., the definition of new smart sensors applied to short-range sensing and devoted to robotics or automotive and industrial fields. In these processes, it is not always possible to reuse directly techniques of remote sensing for short-range sensing : for example, pulse radar does not still work because the pulse length needed becomes dramatically short. Recent papers describe feasibility experiments related to the localisation of a moving body, on a flat surface near of one or several square meters [1], an anti collision process and level measurements using microwave interferometry [2].

We present here examples of other possibilities :

An inclinometer :
Considering a transmitter and two receiving antennas, with the same boresight, located on the same line parallel to a reflective area. The phase shift between the two received signals depends on the angle that make the straight line and the reflecting plane. Consequently, a process able to estimate the non-parallelism between two flat surfaces is achieved by means of two receivers. Their baselines, have the shape of a cross and define the reference plane; the transmitter is located at the center of the cross. We present and discuss the capability of a prototype.

Positioning on a flat area :
A system such as GPS brings already interesting solutions, but its accuracy is limited. We are interested in process providing a better accuracy, but for restricted area, using an equipment much simpler than GPS. A solution has already been brought in [1]. We have now a more interesting solution in which the detectors are above the area under investigation [3]. Results of simulations and experiments achieved with prototypes, for areas between one and thousand square meters will be presented in the communication.

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Microwave Sensors for the Characterization of Dielectric Materials

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Investigations carried out in the last few years have revealed considerable variability in the ability of microwaves to make a breakthrough in the domestic and industrial domains. We can mention two undeniable success which are the microwave oven and the telephone market, but concerning the others application fields, as for example the characterization of dielectric materials, from an industrial point of view, it seems that microwave techniques find it very difficult to assert themselves.

The rapid expansion of personal and satellite communications which resulted in an increased demand of microwave components is a very important asset for the development of new sensors. Actually, around 2 GHz and 10 GHz the cost reduction of the microwave components should give rise to competitive systems in term of price and reliability.

For our part we try to conceive and develop such sensors, two examples are given in this paper.

Sensor for wave guide measurements:

This work originated some years ago in studies of the characterization of the dielectric properties of solid materials such as caster sugar and sand. Then our attention has been attracted to the characterization of web materials and more particularly to textile webs. So, we have developed a system based on the use of an IQ demodulator associated to a slotted wave guide to fulfil this demand [1].

Sensor for free space measurements:

The industrial environment requires devices that can measure materials with minimum disturbance of the process. A response to this constraint is the use of contactless techniques such as free space measurements. For this purpose, we have developed systems operating at 2.45 GHz and 10 GHz, which are able to measure the reflection coefficient of a material under test. Associated to this apparatus, a simplified model which described the propagation between a horn antenna connected to the system and a metal-backed sample has been put in place [2]. Thus, we have been able to characterize materials such as wood or sand in terms of permittivity and moisture. Another application treated with this technique concerns level measurements [2]. At the moment this model imposes to be in far field conditions, but a model which will break this limitation is under study.

Experimental and theoretical studies concerning the determination of the scattering parameters of heterogeneous materials are also under investigations.

References

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