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Instrumentation for the Measurement and Modeling of Micropatch Antennas Controlled with Embedded Impedance Elements

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13. ABSTRACT *(Maximum 200 Words)*
This grant provided the equipment necessary to upgrade the Antenna Systems Laboratory(ASL) thus enhancing our measurement, analysis and simulation capabilities. The Lab supports three graduate assistants and two undergraduate students. In addition a summer program supporting local area High School students is part of the funded lab activities. The funding from this grant has allowed the purchase of new instrumentation for antenna measurements in the anechoic chamber, and for measurements of passive device characteristics in the lab. Additional computational power in support of the modeling effort has also been provided from these funds. In addition to antenna research the Lab has established a web page for dissemination of information about the lab. The web page has a Journal section where all internal ASL reports are available for reading. Some of the reports are further edited to produce papers for submission to outside journals. The ASL Journal provides a method of rapid dissemination of information in more detail that is typically allowed in journal articles. We have found this vehicle to be extremely important for disseminating information within the Lab and also as a breeding ground for outside publications. Current research is directed toward the development of a phase controlled micropatch antenna with the controlling element wholly contained within the patch itself. To date we have produced such a device at 2 GHz and are now transferring the technology to a patch at 10 GHz

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Final Report

Instrumentation for the Measurement and Modeling of Micropatch Antennas Controlled with Embedded Impedance Elements

Principal Investigator
Michael H. Thursby, Ph.D.

Dates Covered;
August 1, 1996-July 31, 1997

Airforce Office of Scientific Research
Grant number, FO8671-9601357

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Abstract

This grant provided the equipment necessary to upgrade the Antenna Systems Laboratory(ASL) thus enhancing our measurement, analysis and simulation capabilities. The Lab supports three graduate assistants and two undergraduate students. In addition a summer program supporting local area High School students is part of the funded lab activities. The funding from this grant has allowed the purchase of new instrumentation for antenna measurements in the anechoic chamber, and for measurements of passive device characteristics in the lab. Additional computational power in support of the modeling effort has also been provided from these funds.

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Objectives

To augment the instrumentation capability of the Antenna System Laboratory in association with the study of the ability to control the far-field phase of micropatch antennas and the application of this technology to multi-element phased arrays. The theoretical effort on this project is directed towards further understanding and optimizing the antenna and the phase shifting properties of embedded impedance elements. A design goal of this project is to develop a methodology that will allow the engineer to design a phase controled element to be incorporated into a steerable array of such elements. The experimental effort is directed towards the verification of the far-field phase control in actual micropatch antennas and arrays of these antennas operating at 10 GHz. The effects of mutual coupling are also being studied.

Status of effort

We have characterized the existing anechoic chamber in the ASL for amplitude and phase characteristics at 10 GHz. A model of the performance has been developed and is being tested. This model will account for chamber effects when measuring the actual antenna and array performance.

Several 10 GHz test candidate antennas have being prepared. Their designs were carried out using Hewlett Packard Momentum electromagnetic simulator. Momentum is also being used to predict the far field pattern of the antennas.

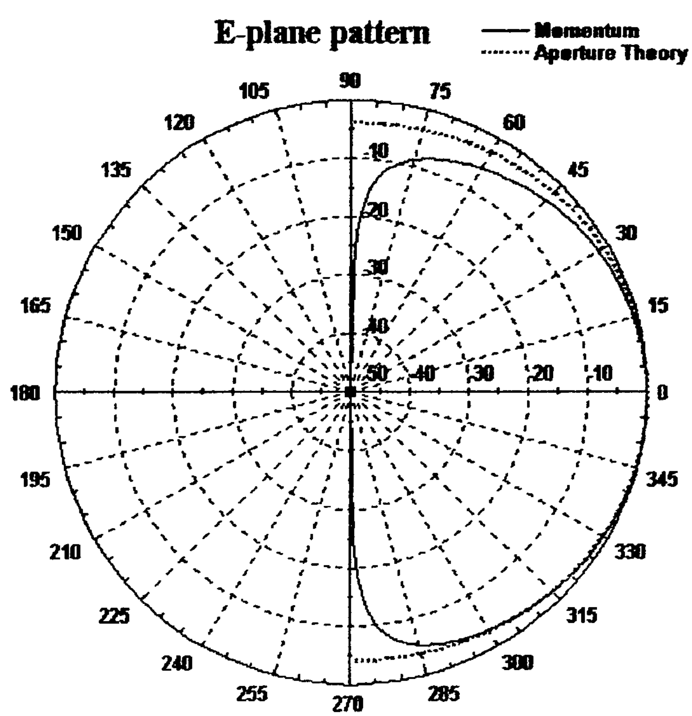

Figure1. Far Field Pattern Model using Momentum compared with bsic aperature theory.

Radiation measurements have been made on one of the 10 GHz single elements and a four element array. We have also measured their circuit performance and find their characteristics to be nominal for such an antenna. With that benchmark we are proceeding to modify the patch design to allow embedding of the control diodes into the elements.

An eight element 10 GHz linear patch array, will be constructed based on our existing four-element test array. The smaller array was built so that we could evaluate the design and evaluate inter-element interaction.

We have successfully measured both magnitude and phase in the chamber at 10 GHz. The chamber phase characteristics are repeatable thus allowing easy compensation. Currently a 1:4 Wilkinson power splitter is being fabricated for the sub-array. Test of this splitter will begin in the next few weeks. Initial cables to the test antenna in the chamber have been replaced with wave-guide to increase the measurement signal to noise ratio. With the installation of the wave-guide an improvement of 20dB has been realized in the measured signal.

Accomplishments and new findings

We have achieved a number of successes during our first year of activity on this program. Detailed technical reports are available at our web site. http://www.ee.fit.edu/electrical/asl_page/ A brief summary of these papers follows this section. Several of the papers appearing on our web site have been revised for publication and have been submitted for review to IEEE journals.

In the process of achieving our stated goals for this we have achieved the following results and milestones during the past year.

Anechoic chamber characterization

As part of our measurement calibration phase we have spent considerable effort to characterize the existing anechoic chamber with respect to amplitude and phase characteristics.

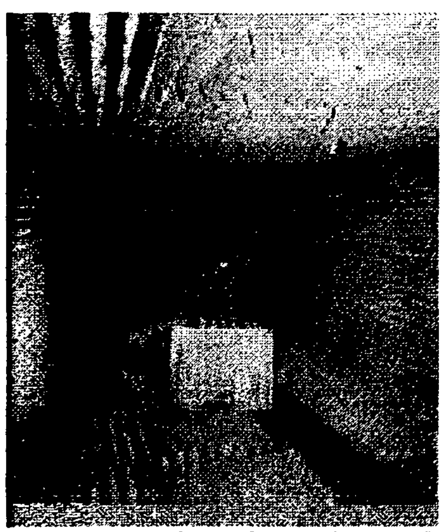

Figure 2. The anechoic chamber showing a single micropatch test antenna installed on the azimuth positioner

The results of this effort have given us a quiet zone in the chamber of approximately four cubic feet at ten gigahertz. Description of these measurements and the results are summarized in the ASL Technical Journal (see abstracts below.) This is large enough to measure the array without an associated ground plane, however with out this ground plane we cannot remove the edge scattering effects of the finite antenna size. We are currently looking at methods of achieving edge effects de-embedding in the existing chamber.

Ten GHz antenna design

In changing the designed operating frequency of our research antennas from 2 GHz to 10 GHz we needed to refine the design rules for the patch and substrate for a conventional antenna first. Then we could modify these rules to accommodate the embedded impedance elements. This work has resulted in several test candidate antennas, which are being studied at this time.

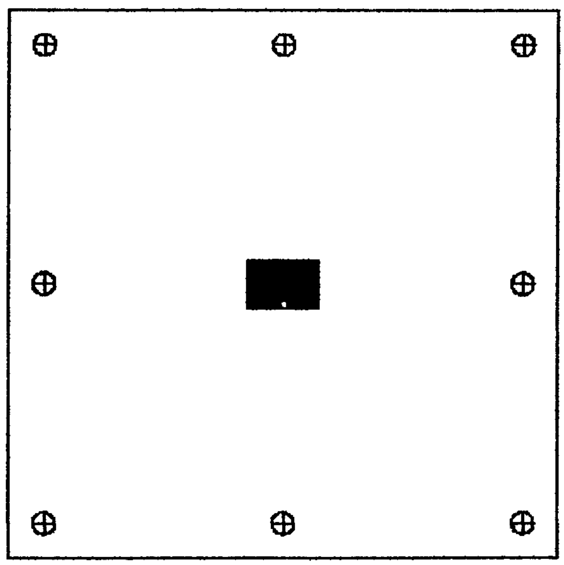

Figure 3. Layout artwork for the 10 GHz patch antenna with radiating patch in the center and mounting holes identified on the periphery.

The theoretical design is being carried out using HP Momentum, a method of moments electromagnetic simulator. The results of this preliminary design effort are summarized in ASL Tech. Journal Report Nr. 1. Preliminary measurements of circuit characteristics of the antennas designed using these new design rules match the predicted results closely. Radiation measurements have been made and the results are being compared with the predicted data.

The control of the array hinges on the embedding of variable impedance elements into the patch. At ten GHz the packaging of the device and its placement in the patch are critical. We have been working on the embedding procedure and at present we are testing a new diode that is very small and has a minimum lead inductance. The diode is of a size that will allow it to be wholly enclosed in the antenna element. Previous attempts to use other diodes with larger packages failed due to the parasitic reactances from the packaging structure.

Ten GHz array design

Prior to the final design of an eight element 10 GHz linear patch array, we have designed an intermediate four-element test array to evaluate the design and the inter-element interaction. This array has been measured and the results are being compared with the predicted results.

Fabrication of 10 GHz patch antenna element

As mentioned above the first set of ten GHz patch antennas have been fabricated. We have measured their circuit performance and find them to be satisfactory so that we can proceed to the pattern measurements, and ultimately to embedding the control diodes into the elements.

Testing of a 10 GHz antenna element

Circuit parameters

Preliminary results indicate that the patch has about 6.8% bandwidth and input impedance of nearly 50 Ohms.

Radiation Characteristics

Modeling of the antenna/Comparison of measured and predicted data are under way at this time.

Measurement the "Quiet Zone" characteristics of the current chamber.

Linear positioner measurements have been completed resulting in a characterization of the chamber as it exists at this time. Both magnitude and phase have been measured at 10 GHz.

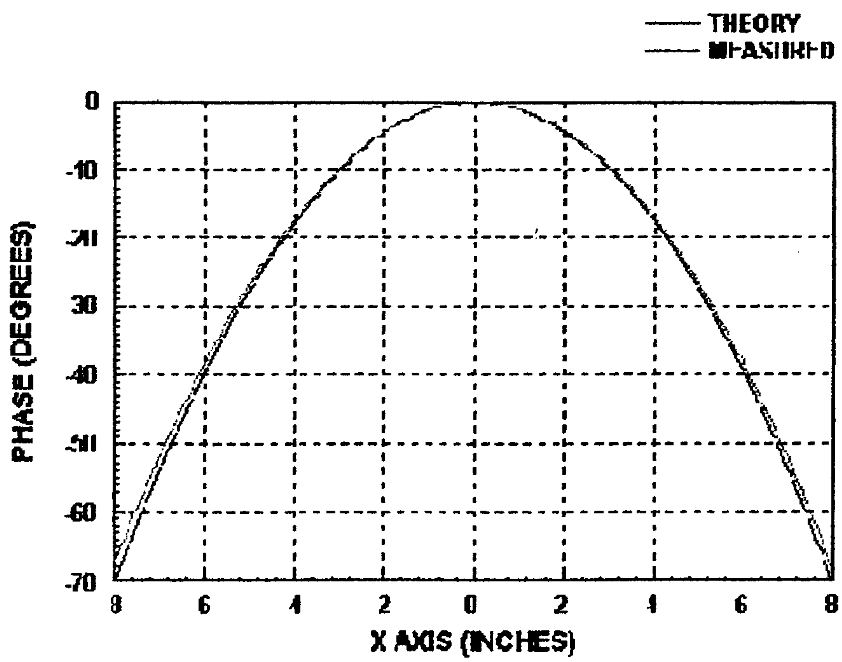

Figure4. Theory vs. measured quiet zone phase for a pair of horn antennas

The amplitude response of the chamber is quite well behaved. as can be seen in the report of the measurement found in the ASL Tech. Journal. The phase characteristics are well behaved but the area of linear phase is quite small which after consideration will always be true. The chamber phase characteristics can be measured and are repeatable so they lend themselves to compensation

Feed structure design for 10 GHz array.

Currently a design for a one-to-four Wilkinson power splitter is being developed for the four-element sub-array. Several of the combiners have been fabricated and are under test now. Following these tests and any required redesign we will incorporate them into the four-element sub-array for testing.

WEB activities

As part of the ASL activities we have an extensive Web Page that includes the Antenna System Technical Journal. This section provides a forum for rapid dissemination of results developed in our lab. The journal contains a number of papers describing in detail the work being carried out in the lab. The reader is invited to peruse the ASL web pages by setting their browser to http://www.ee.fit.edu/electrical/asl_page/. Also, the web pages contain information about the personnel working at the lab including their research activities and interests.

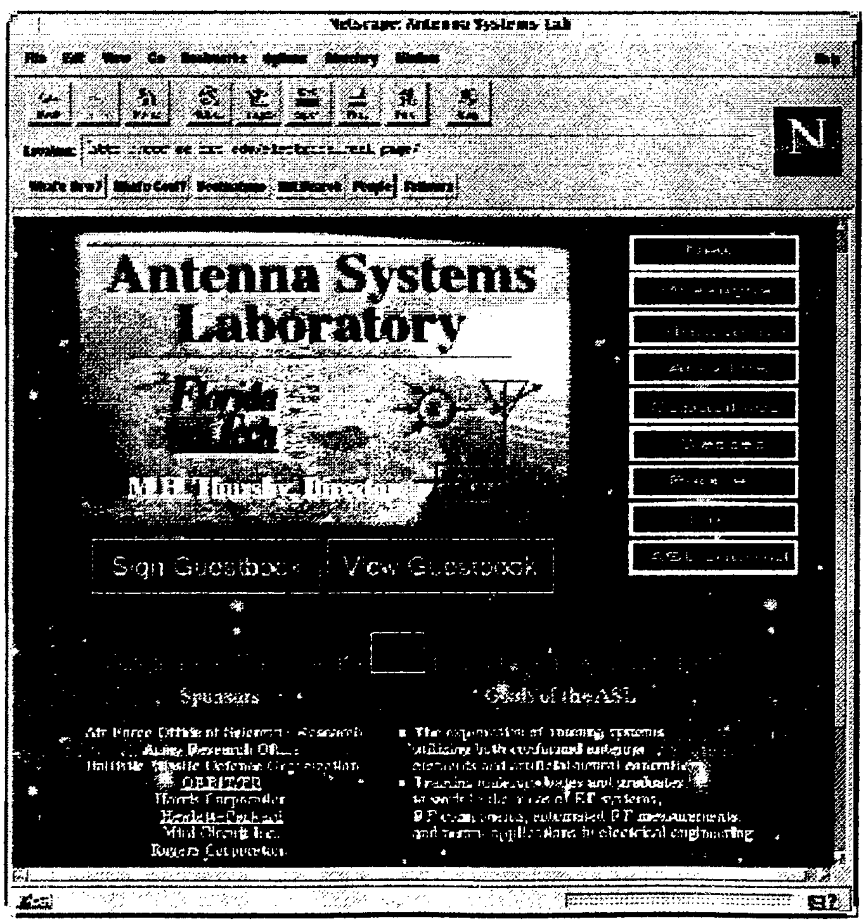

Figure 5. ASL Home Page

Antenna Systems Lab Technical Journal Synopsis

What follows are abstracts of the papers currently found in the ASL Technical Journal.
An asterisk indicates the paper has been submitted for publication, and double asterisk indicated that it has been accepted for publication.

Report Number 1

DESIGN OF A 10 GHZ RECTANGULAR MICROSTRIP PATCH ANTENNA USING HP MOMENTUM

Heriberto J. Delgado

This report presents a design of a rectangular microstrip patch antenna that operates at 10 GHz. Predicted data are shown for input impedance and radiation patterns. The artwork is included at the end of the report. The tool used was HP Momentum. Aperture theory and modal analysis were used to explain the TM01 mode present in the patch, and the results from this theory were compared to the data from Momentum. The data presented should correlate well with experimental data provided that the same dielectric material is used.

Report Number 2 **

DERIVATION OF THE SMITH CHART EQUATIONS FOR USE WITH MATHCAD

Heriberto J. Delgado

In this Appendix, the equations needed to construct a Smith Chart using MathCAD are derived. MathCAD is a very powerful interactive mathematics program. Since there are no Smith charts graphs available in this package, the equations must be written in a way that they can be programmed conveniently. The MathCAD simulation is presented in the Appendix

Report Number 3

DERIVATION OF THE PYRAMIDAL HORN RADIATION PATTERN EQUATIONS FOR USE WITH MATHCAD

Heriberto J. Delgado

In this report, the far field radiation pattern equations for the pyramidal horn antenna are derived. This horn was used as a transmitting antenna for an anechoic chamber, and its radiation pattern magnitude and phase are needed in order to compute the quiet zone fields at the receiving antenna. The equations are derived in detail, and a MathCAD v. 7.0 simulation is presented in Appendix A, where the far fields are computed, as well as the horn directivity.

Report Number 4

DERIVATION OF THE OPEN-ENDED WAVEGUIDE RADIATION PATTERN OVER AN INFINITE GROUND PLANE

Heriberto J. Delgado

In this report the far field radiation pattern for an open-ended waveguide, over an infinite ground plane, is derived. Since the radiation properties of this antenna are well known, the open-ended waveguide can be used to quantify the accuracy of the experimental set-up. The equations are derived in detail, and a MathCAD v. 7.0 simulation is presented in Appendix A.

Report Number 5

Phase Model for a Sectoral Horn Antenna

Young-Min Jo

A horn antenna is the one of the most useful antennas for building a wave model and taking measurement. Magnitude of a far field wave for a horn antenna is almost the same as a plane wave. However, far field phase doesn't look like plane wave because phase is only related to the path length from source antenna to measuring point. A phase model for the horn antenna is built with an antenna geometry and far field geometry. Also, it is derived by antenna characteristic equations shown in related books. The phase measurement is taken in an anechoic chamber. H-P 8720 Vector Network Analyzer is used to obtain the s-parameters for the antennas. Also, MATLAB is used to analyze the model and measured data. Consequently, comparison is made between the model and the measurement.

Report Number 6

ANTENNA CHARACTERISTICS AND QUIET ZONE FOR VARIOUS ANTENNAS

Young-Min Jo

When waves are propagated in the chamber, there is an area called quiet zone where the waves look like plane wave. Results for three kinds of horn antennas (3-inch sectoral horn, 5-inch sectoral horn and 5-inch exponential horn.) and two kinds of reflector antennas (2 feet reflector antenna and 4 feet reflector antenna) used as a source antenna are presented. Also, a probe antenna located on a linear positioner is used as a receive antenna. The data is measured with HP 8720 Vector Network Analyzer and transmitted to Sun-Sparc workstations for the analysis and plotting. It is normalized to obtain quiet zones for phase. Plus-minus 5 degree is considered as a reasonable normalized phase value for the quiet zone. Also, plus-minus 1~2 dB is considered as a reasonable magnitude. Comparisons among the quite zones are made.

Report Number 7

DERIVATION OF THE RECTANGULAR MICROSTRIP PATCH ANTENNA RADIATION PATTERN FOR AN ARBITRARY TM(M,N) MODE OVER AN INFINITE GROUND PLANE

Heriberto J. Delgado

In this report, the far field radiation patern equations for the rectangular microstrip patch antenna are derived. Expressions are derived for an arbitrary mode, for the co-polar and cross-polar pattern cuts. In addition, the equations for the directivity and the surface currents are presented. The practical implementation of the equations are illustrated in a MathCAD v. 7.0 simulation, which is included in Appendix A

Report Number 8

MODELING OF MICROSTRIP AND WAVEGUIDES ANTENNAS MOUNTED ON CIRCULAR GROUND PLANES USING GTD

Heriberto J. Delgado

The radiation pattern of microstrip and open-ended waveguides antennas mounted on finite ground planes can be calculated by the superposition of the far field pattern of the antenna over an infinite ground plane, which is the geometrical optics field, and the edge diffracted fields. In this report the Geometrical Theory of Diffraction (GTD) analysis equations are derived and used for the prediction of the total far field radiation pattern of an antenna mounted on the surface of a circular ground plane. The expressions for the far field radiation patterns of a rectangular microstrip antenna and an open ended waveguide over an infinite ground plane were obtained from ASL Reports 4 and 7. [1], [2]. A MathCAD v. 7.0 simulation is presented, that ilustrates the practical application of the equations derived.

Report Number 9

FIELD ANALYSIS USING A HORN ANTENNA IN THE QUIET-ZONE

Young-Min Jo

A far-field measurement system in Antenna Systems Laboratory at Florida Tech is presented. Measurement for a sectoral horn antenna is undertaken. The result is demonstrated by a computer tool. The far-field model for the horn antenna that is used as a source antenna is presented. Computer simulation is used to configure this model. The comparison between the model and the measurements is made. Phase and magnitude error plots are presented.

Report Number 10

DERIVATION OF THE OPEN-ENDED WAVEGUIDE ANTENNA RADIATION PATTERN IN FREE SPACE

Heriberto J. Delgado

In this report the far field antenna radiation pattern equations for an open-ended waveguide, in free space, are derived and implemented. The equations are formulated in detail, in order to provide physical insight into the radiation mechanisms of the antenna. The application of these equations to a real antenna problem is illustrated with a MathCAD version 7.0 simulation, in Appendix A.

Report Number 11

ANECHOIC CHAMBER QUIET ZONE ANALYTICAL AND EXPERIMENTAL CHARACTERIZATION FOR VARIOUS TRANSMITTING ANTENNAS

Heriberto J. Delgado and Young-Min Jo

In this report the antenna pattern measurement set-up at ASL is described in detail, the quiet zone is analytically computed for three different transmitters, and then compared to measured data. A simplified, yet accurate, quiet zone phase model is also derived assuming that the transmitter is a point source.

Report Number 12

MEASURED AND THEORETICALLY PREDICTED WITH GTD ANTENNA RADIATION PATTERNS FOR A WR90 WAVEGUIDE USING VARIOUS TRANSMITTING ANTENNAS

Heriberto J. Delgado

In this report, antenna radiation patterns for a WR90 open-ended waveguide, mounted on the surface of a circular ground plane, are presented. The frequency used was 10 GHz. In addition, the input impedance is presented. The transmitting antennas are two pyramidal horns and a WR90 waveguide. Measured and predicted radiation patterns are compared. The predicted radiation patterns were computed using aperture integration and the Geometrical Theory of Diffraction (GTD) [1]. Finally, quiet zone statistical parameters [2] are used, in conjunction with measured peak power levels, for the selection of the transmitting antennas that are more suitable for accurate pattern measurements. The small pyramidal horn transmitter provided the best agreement between measured and predicted. However, the WR90 waveguide can provide more accurate measurements if the power levels are increased by a minimum of 10 dB.

Report Number 13

COMPUTATION OF RMS VALUES FOR MEASURED ANTENNA RADIATION PATTERNS

Heriberto J. Delgado

In this paper, the algorithm for the rms computation is presented. The E-plane unprocessed magnitude and phase patterns are also shown. In addition, one angle in the pattern frontside, and two angles in the pattern backside, are used for these measurements. The results are then summarized in a table.

Report Number 14

ANTENNA PATTERN SUBTRACTION MEASUREMENT TECHNIQUES AND TIME DOMAIN MEASUREMENTS USING A WR90 OPEN-ENDED WAVEGUIDE

Heriberto J. Delgado

In this report, a pattern measurement technique, called the subtraction technique, for eliminating the edge diffraction from antenna patterns is presented. A WR90 waveguide, mounted on a 16" circular ground plane is used for the measurements. The subtraction technique is based on the property that the edge diffracted electromagnetic fields on the front and back sides of an electrically thin ground plane are equal in magnitude. Therefore, the effects of edge diffraction on the frontside pattern can be eliminated by subtracting the edge-diffracted fields measured on the backside. Time domain signals at the frontside and at the backside are used to illustrate the presence of the direct and diffracted fields, and how the diffracted fields are eliminated in a straightforward fashion. The Fourier transform algorithm used to convert the frequency domain responses to the time domain is presented in Appendix A, and the MathCAD implementation is shown in Appendix B. Finally, the subtraction technique is illustrated with a measured E-plane radiation pattern. The results were not very good, since more accuracy is needed in the pattern measurements; however, the process needed to eliminate the edge-diffracted fields was presented. The MathCAD simulation for the processing of the measured data using the subtraction technique is presented in Appendix C.

Report Number 15

RECTANGULAR MICROSTRIP PATCH ANTENNA DIELECTRIC CONSTANT AND SMA CONNECTORELECTRICAL DELAY COMPUTATION

Heriberto J. Delgado, Young-Min-Jo, Sean F. Sullivan and Ovidio M. Oliveras

In this report, the iterative computation of the microstrip patch antenna substrate dielectric constant, and the SMA connector electrical delay are presented. The computer modeling tool used is HP MDS Momentum. The initial patch dimensions are computed by scaling the dimensions of a 3 GHz patch antenna. Then, the input impedance is measured and compared to the theoretically computed data. At this time, the substrate dielectric constant and the SMA electrical delays are computed, and the patch is analyzed with HP MDS Momentum again. Then, the newly correlated data is shown, where it can be seen that there is good agreement between measured and predicted data. The S11 parameters magnitude and phase are plotted in rectangular plots. In addition Smith charts, VSWR plots, and radiation patterns are presented. Furthermore, the anechoic chamber configuration is described. The transmitter reflector antenna geometry is presented in Appendix A, and the quiet zone performance is shown in Appendix B. The SMA connector electrical delay calculation is shown in Appendix C.

Report Number 16

VALIDATION OF PREDICTED HP MDS MOMENTUM INPUT IMPEDANCE DATA USING MEASURED DATA FOR A RECTANGULAR PATCH MICROSTRIP ANTENNA

Heriberto J. Delgado and Sean F. Sullivan

The extraction of information by observing measured data, while comparing it to analytical data, can provide invaluable insight into the patch antenna manufacturing process. This information is very important when large antenna arrays are to be fabricated, where the processes which experience the most variability can be improved, in order to obtain a better system performance. In this report, the statistical results obtained from the fabrication and the measurements of four rectangular microstrip patch antennas, are presented. The S11 was measured and compared to the predicted data. The modeling tool was HP MDS Momentum. The patch geometry is shown, and S11 magnitude, phase and Smith charts are presented. In addition, the statistical results are included in a summary table.

Personnel;

Dr. Michael H. Thursby, Principal Investigator
Mr. Young-Min Jo, Ph.D. Student
Ms. Carole Fonck, M.S. Student
Mr. Sean Sullivan M.S. Student
Mr. Ovidio Oliveras B.S. Student
Ms. Christina Rivera B.S. Student

Peer reviewed publications

Two Publications behave been submitted for review.

Interaction/Transition

Who; Rome Lab East
Hanscom AFB, Ma.

Point of Contact; Dr. Hugh Southall

Discussions with Dr. Southall have led to the development of the 10 GHz antenna being used for the design and evaluation of the concept. The development of the eight element array will fit into a program within this group also. Our interaction with Dr. Southall and his associates continues.

Who; Dr. M. Thursby
IEEE International Microwave Symposium 1998

Dr. Thursby continues to serve on the Microwave Theory and Techniques Technical Program Committee for the Symposium. This past year he was the session chair for the Phased Array Session, where a number of excellent papers were presented on current research.