1990 URSI
RADIO SCIENCE MEETING
International Union of Radio Science

PROGRAM AND ABSTRACTS

May 7–11
Dallas Convention Center
Dallas, Texas

TECHNICAL PROGRAM SUMMARY

Room	MONDAY, MAY 7	TUESDAY, MAY 8	WEDNESDAY, MAY 9	THURSDAY, MAY 10
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W101	13 Electromagnetic Topics			

NATIONAL ACADEMIES OF SCIENCE AND ENGINEERING
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1990 RADIO SCIENCE MEETING

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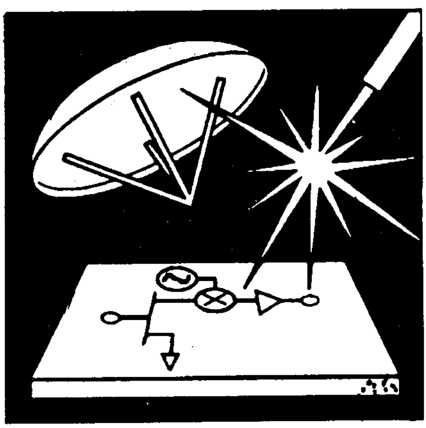

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DALLAS, TX
MAY 6-11, 1990

WELCOME TO DALLAS

On behalf of the symposium steering committee, I extend a warm welcome to big 'D'. This year, the AP-S and URSI organizations join with the Microwave Theory and Techniques Society (MTT-S) for the AP-S/URSI/MTT-S Joint International Symposium. More than one-third of the AP-S and URSI members are also members of the MTT society and likewise more than one-third of the AP-S chapters worldwide are joint MTT-S/AP-S chapters. The societies share a common heritage and continue to benefit from the advances occurring in shared technologies. It is therefore natural for the societies to have a "get together" once a decade (last one held at Los Angeles in 1981) to assess the state of common technologies.

A record of 850 papers, evenly split between APS and URSI, were submitted for review by the Technical Program Committee. As in the past, papers will be presented on a wide range of topics with the strongest concentration in EM theory, numerical methods, scattering and diffraction, microstrip antennas, reflectors, antenna theory, and phased arrays.

Special Sessions honor the contributions of Professors Leopold Felsen of the Polytechnic University and Y.T. Lo of the University of Illinois. In addition there are focused Special Sessions on polarimetrics, superconductivity, digital beamforming, scattering from antennas, innovations in EM education, fiber optic applications to phased arrays, millimeter wave components and phased arrays, time domain analysis of planar circuits, the role of analysis in the age of computers, and reducing the operation count in EM modeling.

A highlight of the technical program will be the plenary session held jointly with the MTT Society. Our plenary speakers; Dr. Harold Sobol of the University of Texas at Arlington, Dr. Robert Mailloux of Rome Air Development Center and Mr. Richard Mathison of Jet Propulsion Laboratory will give their views on how different technologies will be merging in the coming decade to influence systems of the next generation. Eight short courses and workshops will be held on Friday. They include, Application of Lightwave Technology to Microwave Antennas, Computer Application in EM Education, EM Modeling Software Validation: Benchmark Solutions, Broadband Low-Profile Antennas, Analysis and Design of Microstrip Antennas, Finite Element Methods, State of the Reflector Antenna Art in the 1990's, and Fundamentals of Microwave Radomes.

The social program is packed with both daytime and evening events. The kick-off event will be the AP-S/URSI reception at the Dallas Convention Center on Sunday evening. On Monday there will be a Horizon House reception at Longhorn Ballroom. The awards banquet will be on Tuesday night. Finally on Wednesday, you will have an opportunity to spend an evening at a Texas Ranch.

This outstanding program is possible only by the contributions of the authors and the dedicated work of several steering committee members I want to express my thanks to all of them.

Shashi Sanzgiri
Chairman, Steering Committee

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Monday AM
URSI-B Session 1
Numerical Methods I

Chairs: Steven M. Wright, Texas A&M University; Joseph R. Zinecker, LTV
Room: W-107 *Time*: 8:15-12:00

IMPROVED FFT ANALYSIS OF FINITE PERIODIC ANTENNA ARRAYS

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It is well known that the input impedance of an isolated antenna element can be obtained from the infinite array formulation by integration of the infinite array scan impedance (Munk and Burrell, *IEEE Trans.*, AP-27, No. 3, May 1979.) More recently, Ishimaru and co-workers have developed a related technique called the Finite Periodic Structure method which obtains the input impedances of the elements in a finite array from the infinite array formulation (Ishimaru *et. al.*, *IEEE Trans.*, AP-33, No. 11, Nov. 1985.) Implementation of both methods requires sampling the active impedance of the infinite array as the main beam is scanned over one period of the reciprocal lattice.

A limiting factor in both methods is the large number of scan angles for which the infinite array impedance is required. However, once these values are calculated for a given array structure, the element impedances for any arbitrary excitation of a finite array can be efficiently computed by FFT. The accuracy of the method is dependent upon the number of samples used in the FFT. To allow large numbers of samples we have used an efficient infinite array solution based upon the accelerated periodic Green's function to calculate the impedance values (Lo, Wright and Davidovitz, Ch. 13, Hdbk. Microwave and Optical Comp., Vol. 1, Kai Chang, ed., Wiley, 1989.) In addition, the 2-D grid of scan impedance values is filled using an adaptive algorithm, interpolating between calculated samples where the array impedance is slowly varying. Using these two techniques, very large FFT matrices can be used for improved accuracy. Additionally, the dense sampling of the scan impedance has allowed the method to be extended to the analysis of finite arrays of microstrip antennas by adding a small amount of loss to the superstrate and/or substrate layers.

The effect of the size of the FFT matrix and the loss tangent on the accuracy of the results and execution times will be examined. Results for finite free-space arrays and microstrip arrays will be compared to published results and results obtained from standard moment-method techniques.

NUMERICAL COMPUTATION OF HIGHER-ORDER MODES IN A SHIELDED MICROSTRIP LINE

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The spectral domain approach (T. Itoh, MTT, July 80, p. 733-736) was used to formulate the numerical calculation of higher-order modes in a shielded microstrip line. Using entire domain basis functions, the method of moments was used to implement the formulation on the computer. It was found that the modes in the shielded microstrip line were similar to the modes in an empty waveguide and that the addition of an inner conductor and a slab of dielectric could be viewed as perturbations to the fields of the empty waveguide. The effect of the dielectric, as expected, was to concentrate the field in the dielectric and to lower the resonant frequency. The effect of the inner conductor depended on the particular mode (LSE or LSM), its orientation with respect to the field lines, and its width. Results, including modal frequencies, streamline plots, and dispersion curves, will be presented.

Emphasis will be placed on the accuracy and efficiency of the computer code so that it can be used for further analysis, such as mode matching. The accuracy was determined by checking the tangential electric field on the inner conductor. A figure of merit, the RMS error, was computed as a comparison (a) in using different basis functions, (b) in using a different number of basis functions, and (c) in the optimum placement of the testing functions.

Verification of the formulation and computer code was accomplished not only by using a boundary condition test on the inner conductor, but also from a comparison with other authors, and by experiment.

A NEW TIME DOMAIN METHOD IN SOLVING GUIDED-WAVE STRUCTURES

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University of Texas at Austin
Austin, TX 78712

A new time domain method is employed to solve the wave propagation problem along the guided wave structure in a waveguide type enclosure. The proposed method basically utilizes the wave scattering idea in the time domain. The structure under analysis is a microstrip inside a rectangular waveguide which is separated into two homogeneous regions: air and dielectric. Each of the two sub-structures is a semi-infinite parallel plate waveguide. The wave propagation phenomena inside the individual regions will be replaced by the time domain Green's function, i.e., impulse response. If the impulse response of the individual semi-infinite parallel plate waveguide is known, the time history of the electric field at the interface is obtained through the convolution integral of the impulse response and the input function. Since the structure is cut into two halves, at any time instant, the field scattering out of region 1 will be going into region 2 and vice versa. The interface is also discretized to account for the fact that the interface has conducting strips located somewhere. The whole problem is reduced to solving the wave propagation at the interface which is done by matching the boundary conditions. The boundary conditions at the air-dielectric interface is satisfied at every time step depending on the natures of the nodes. Therefore, the time history of the total electric field at the interface can be recorded and used to calculate the frequency domain information through the Fourier transform.

The difficulty of the method falls on the calculation of the impulse response. The impulse response used here is obtained from the inverse Laplace transform of the frequency domain Green's function of the semi-infinite parallel plate waveguide. The impulse response has an analytical expression which basically is the summation of the Bessel function of the first kind. Each term inside the summation corresponds to one mode in the frequency domain having the following functional form:

$$g_n(t) = c\frac{n\pi}{a}2l\frac{J_1\left(\frac{n\pi}{a}\sqrt{c^2t^2-(2l)^2}\right)}{\sqrt{c^2t^2-(2l)^2}}$$

in which, c is the velocity of light in free space, a is the height of the rectangular waveguide, l is either the thickness of the substrate or the air and n is the mode number. When n is large, the Bessel function oscillates very rapidly. In order to pick up the variations of the function, the time stepping has to be very small. Consequently, the number of time steppings needs to be large and the required CPU time of the calculations increases.

The method is used to calculate the resonant frequencies of a empty rectangular waveguide for the lower order modes. The results agree very well with the analytical results.

A RECURSIVE ALGORITHM FOR CALCULATING THE SCATTERING FROM STRIPS OR PATCHES

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ABSTRACT

In recent papers, we have introduced the concept of reflection operators [*IEEE Trans. Microwave Theory Tech.*, vol. MTT-36, pp. 1488–1497, Nov. 1988] and the recursive computation of these operators [*IEEE Trans. Antennas Propagat.*, accepted for publication, Apr. 1989]. Our previous recursive algorithm requires $O(N^3)$ operations, where N is the total number of unknowns in the problem. This complexity is the same as that of a matrix inversion routine that is needed in an ordinary moment method computation.

In this paper, an alternative formulation of our previous recursive relation is shown resulting in an $O(N^2K)$ algorithm. K is the largest number of spectral points at which one needs to sample the integrand of a reaction integral of the type

$$\int_{-\infty}^{\infty} dk_x\, f_i(k_x) G(k_x) e^{ik_x(x_i-x_j)} e^{ik_z|z_i-z_j|} g_j(k_x)$$

so that one can obtain an accurate numerical approximation to all the integrals of this type arising in the specific problem. $f_i(k_x)$ and $g_j(k_x)$ are any current basis and testing functions and $G(k_x)$ is the spectral Green's function. By keeping K as a constant that is independent of the increase of N, we show that the complexity of this algorithm reduces to $O(N^2)$.

This algorithm is illustrated by solving scattering problems of conducting strips and patches in homogeneous media. However, this formulation can be used to solve many electromagnetic problem (guidance, resonance, radiation, etc.) that can be defined on an arbitrarily complex geometry of strips or patches embedded in an arbitrarily layered medium [*IEEE Trans. Microwave Theory Tech.*, vol. MTT-36, pp. 1498–1506, Nov. 1988].

A COMPARISON OF PARTIAL DIFFERENTIAL EQUATION BASED DISCRETIZATIONS OF MAXWELL'S EQUATIONS IN THE TIME AND FREQUENCY DOMAINS

*Scott L. Ray**
Lawrence Livermore National Laboratory
Andrew F. Peterson
Georgia Institute of Technology

Frequency domain results can be generated by several different approaches. The more obvious and direct method is to use a code that solves Maxwell's equations in the frequency domain. This approach has the advantage that it provides complete information about the fields at the particular frequency of interest. However, if data are required over a wide frequency range, the code must be re-run at a (perhaps large) number of different frequencies. A second approach is to use a time domain code. In this approach, a broadband source is used to excite the problem and, upon conclusion of the time domain simulation, the results are Fourier transformed to generate frequency domain data. A single run thus generates results over a range of frequencies. However, if the field distribution is desired at a specific frequency, complete time-domain data must be stored and subsequently Fourier transformed at a large number of spatial points. A third approach also involves using a time-domain code, but instead of using a broadband pulse, a sinusoidal excitation is used and the problem is run to steady-state. In this case, Fourier transforms are unnecessary; magnitude and phase information can be extracted by examining the temporal output over the last half period of the simulation. This approach can be quite efficient for low Q problems as the steady-state solution is reached in a short number of periods.

As different approximations are used in the time and frequency domain approaches, different numerical results are expected. Thus, in addition to efficiency, a key issue in comparing these techniques is their accuracy. In this talk, we examine the relative accuracies and efficiencies of these three approaches for the case of 2-D partial differential equation (PDE) based discretizations of Maxwell's equations. These PDE-based methods have become increasingly popular in recent years due to their inherent geometric flexiblity. Effective algorithms for both time and frequency domain electromagnetics have been developed recently using either finite element or finite difference discretizations.

A SYSTEMATIC BASIS FUNCTION CHOICE FOR SPECTRAL DOMAIN ANALYSIS

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H3C 3A7

Spectral domain techniques are increasingly used for microwave hybrid and monolothic integrated circuit analysis. The method consists in writing the fourier transform boundary differential equations and express the charge distribution on the conductors in terms of Gij the Green function. Finally, one compute ρi using Galerkin method.

However, in order to use Galerkin optimization technique, one has to express the charge distribution ρi as a summation of basis functions. The convergence and precision of results is dependent on the proper choice of these basis functions. Although many different circuits configurations have been analyzed in the literature, no systematic algorithm has yet been proposed for the basis function choice.

Microwave integrated circuits can in general be regrouped under four major categories: a) microstrip discontinuties, b) simple configurations such as microstrip lines, multilayered coplanar strips lines, broadside-couples suspended substrate striplines, edge-coupled strip with overlay, coupled stripts with overlay, coupled suspended lines with septums, c) complex configurations such as multiple coupled microstrips, stripline containing a dielectric layers and N interfaces with conductors, broadside-coupled striplines of unequal width, d) configurations involving periodic charge distributions due either to reflections or the structure geometry. For example, unilateral finlines, unilateral finlines with magnetized ferrite substrate, unilateral finlines on an anistropic substrate and periodically non-uniform microstrip lines.

For each category of microwave circuit, it is found that an optimal basis function can be identified as follows: a) Heaviside function, b) Quadratic function, c) Tchebyshev function, weighted by an edge condition, d) Sinusoidal function, weighted by an edge function

A CNTLM SPECTRAL ANALYSIS OF SCATTERING PROPERTIES OF A PERIODIC ARRAY OF DIELECTRIC BARS

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and

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The CNTLM (Condensed Node Transmission Line Matrix) method is used in this paper to compute the spectral response of a periodic structure formed with dielectric bars of different permittivities. Sources of excitation are placed above the periodic structure which is enclosed in a box with absorbing boundaries so that waves originating from within the box are not reflected back into the box; hence, an open space environment is simulated for the CNTLM analysis. The scattering properties of the periodic structure can be studied by recording its transient responses at observation points placed anywhere within the box. A typical location for the observation point is a point above the periodic structure but away from the source point location. These records of transient response are then Fourier transformed to obtain the spectral responses of the periodic structure.

The CNTLM method samples all of the E and H field components at the same point in space. Therefore, it permits accurate modeling of the interfaces between various regions of material within the periodic structure. The approach is a computer simulation of wave propagation on a transmission line matrix. The structure under consideration is divided into various blocks whose material parameters are the same, e.g., the air regions above and below the periodic structure, each of the dielectric bars with different permittivities, and so on. Many iteration time steps are used to compute the transient response until a steady state is reached. To improve the accuracy of the solution, many nodes have to be used to describe the structure. The increasing availability of supercomputers in the 1990's, however, should make the CNTLM method suitable to handle transient analyses of complex structures discussed in this paper.

APPLICATION OF THE PIECEWISE UNIFORM ZONING TECHNIQUE TO TRANSFORM DOMAIN METHODS

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Transform domain techniques require a uniform grid (usually a rectangular one) in order to discretize the convolution integral into a discrete convolution sum. Such a grid will not conform to the curved boundary of a given scatterer and consequently creates rough corners at the boundary. At a certain angle and polarization of the incident wave, this "staircase effect" will cause some inaccuracy in RCS computations. Although it has been observed that a better accuracy can be achieved by using a higher resolution and a more accurate error criterion, the penalty to computing time is extremely high. This is due to the fact that the zigzag at the boundary and the use of a very high resolution tend to slow down appreciably the convergence of the conjugate gradient method (CGM). Thus efforts were made to develop more sophisticated zoning schemes which will eliminate the staircase problem.

For a certain simple geometry (e.g. a triangular-shaped plate), a zoning method based on the superposition of different uniform grids can be used to solve the staircase problem. This piecewise uniform zoning technique will, by and large, preserve the efficiency of the transform domain methods. A detailed discussion on the piecewise uniform zoning technique, together with the related topics on interpolation and parallel computing, will be given. Predictions made by incorporating this zoning scheme with the discrete Fourier transform method (DFTM) show excellent agreement with those of experiments.

USE OF CAUCHY'S TECHNIQUE TO FIND THE ELECTROMAGNETIC RESPONSE OF A CONDUCTOR FROM ITS FREQUENCY RESPONSE SAMPLES

K. Kottapalli, Y. Hua,T. K. Sarkar, and E. Arvas*

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It is usually necessary to compute the electromagnetic response of a scatterer over a given frequency range. This can be done using two techniques. One way is to compute the response and its derivatives at a few frequencies and reconstruct the response the required frequency range. The other procedure is to solve the problem at many frequencies. The first method is pragmatic when there are cases involving resonance as it requires much less cpu time.

In this method we have a complex rational function in this case, the electric current, which is written as a ratio of numerator and denominator polynomials. Our objective is to find the coefficients of the numerator and denominator polynomials. This is done by using the information which we have i.e. the value of the transfer function and its derivatives at a few points. Although we know that the numerator and denominator are polynomials we do not know their orders. This can be obtained using the Cauchy's technique. It can be shown that this technique is unique if the total number of samples is larger than or equal to the total number of coefficients. After we find the coefficients of the numerator and denominator polynomials we can reconstruct the transfer function over a certain frequency bandwidth.

This technique has been applied to find the electric field of a conductor(both closed and slit). Depending on the frequency range of interest we fix the number of frequencies and the number of number of derivatives. Higher the frequency range higher the number of frequencies and/or the number of derivatives. The electromagnetic function involved is the current. The method of moments(pulse expansion and point matching) is used to solve for the current at a single frequency and using the Cauchy's technique the response is reconstructed over the required bandwidth. The results obtained are in good agreement with some of the published data.

APPLICATION OF TRANSFORMS TO ACCCELERATE THE CONVERGENCE OF SLOWLY CONVERGING SERIES

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A problem very frequently encountered in the analysis of periodic arrays is the slow convergence of the series representing the Green's function. This series is an infinite (singly or doubly) series and it converges very slowly whenever the observation point lies near or in the plane of the array. A technique for accelerating the convergence of the series representing the free space Green's function has been suggested (Wilton *et. al.*, Proc. USNC/URSI National Meeting, Houston, TX, p.82, May 23-26,1983). The first method consists of successively applying Kummer's and Poisson transformation to the Green's function series. The second method employs Kummer's, Poisson and Shanks' transforms to accelerate the convergence of the series.

In this paper the results of applying the two acceleration techniques to accelerate the convergence of the free- space Green's functions of the Helmholtz and Laplace equations are presented. It is shown that considerable savings in computation time is achieved by application of the transforms. Numerical results include relative error vs. number of terms, and computation time vs. a pre-defined convergence factor. The advantages and disadvantages of applying the Shanks' transform are discussed. In addition to the two methods , a third method which makes use of Mellin transform is introduced. Results of applying Mellin transform to certain slowly converging series are also presented.

Monday AM
URSI-B Session 3
Microstrip Antennas

Chairs: K. A. Michalski, Texas A&M University; Stuart A. Long, University of Houston
Room: W-116 *Time*: 8:15-12:00

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Tapan K. Sarkar*, Pallab Midya, Syracuse University; Sadasiva M. Rao, Auburn University

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K. A. Michalski*, D. Zheng, Texas A&M University

9:00 **A Novel Log Periodic Microstrip Array** 16
Ahmad Hoorfar*, Villanova University; David C. Chang, University of Colorado at Boulder

9:20 **Layered Tape Dielectrics for Microstrip Patch Antennas** 17
Zahia Drici*, Barry Grossman, Michael Thursby, Florida Institute of Electrical Eng

9:40 **Design of Broadband, Conformal, Spiral Microstrip Antenna** 18
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10:20 **Input Impedance of Microstrip Antenna with Terminated Tuning Stub** 19
K.V. S. Rao*, APREL Inc.; Prakash Bhartia, National Defence

10:40 **Analysis of a Printed Strip Dipole Antenna Used as a Hyperthermia Applicator** 20
Steven L. Dvorak*, The University of Arizona

11:00 **Rigorous Analysis of Scattering from Large but Finite Arrays-Frequency Selective Surfaces and Microstrip Patches** 21
T. Cwik*, Jet Propulsion Laboratory

11:20 **Experimental Verification of the Theoretical Prediction of the Far Field Characteristics of Patch Radiators** 22
L. A. Wegrowicz*, Mitec Electronics Ltd.

11:40 **Gain Enhancement of Microstrip Line Planar Antenna** 23
Chi-Sen Lin*, Shun-Shi Zhong, Jian-Hui Shi, Chong-Bin Yao, Shanghai University of Sicence & Tech.

ANALYSIS OF ARBITRARY SHAPED MICROSTRIP PATCH ANTENNAS ON FINITE SUBSTRATES

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Abstract:

The objective of this presentation is to develop two different approaches for the analysis of arbitrary shaped finite microstrip structures. The dielectric layer and the ground plane are finite in extent. Comparison is made between two different approaches namely: volume/surface formulation and surface/surface formulation. The volume surface formulation utilizes the equivalent volume electric current for characterization of dielectric media and uses the equivalent surface electric current for characterizing conductors. The surface/surface formulation utilizes the equivalent surface electric and magnetic current for characterizing the dielectric body and equivalent surface electric current for conducting bodies. Comparision will be made of both these two technique for the analysis of radiation from finite microstrip structures. Both these techniques are quite accurate and yields acceptable results if implemented intelligently!! Numerical results will be presented to illustrate the accuracy of both these techniques and compared to the Sommerfeld solution which is valid only for infinitely long conductors and dielectrics.

ON THE PERFORMANCE OF SEVERAL COAX–FEED MODELS IN NUMERICAL ANALYSIS OF ARBITRARILY SHAPED MICROSTRIP ANTENNAS

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Microstrip antennas of arbitrary shape driven by a coaxial cable are analyzed using a mixed-potential integral equation formulation (Mosig, *IEEE Trans.*, MTT-36, 314-323, 1988; Michalski & Zheng, *IEEE Trans.*, AP-38, 1990, in print) in conjunction with the triangle-element model of the patch (Rao *et al.*, *IEEE Trans.*, AP-30, 409-418, 1982; Hwu *et al.*, *Digest IEEE AP-S Int'l Symp.*, 890-893, 1988; Pichon *et al.*, *Electron. Lett.*, 24, 1214-1215, 1988). Three different models of the feed structure, varying in accuracy and complexity, are implemented and their performance evaluated by comparison of the computed results with measured data.

A NOVEL LOG PERIODIC MICROSTRIP ARRAY

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As it is well known microstrip-based antennas have many advantages: they are conformal to different surfaces and shapes, and have lightweight, low profile and low production cost. These antennas, however, suffer from a very narrow bandwidth, typically 2 to 4% for a patch element. Thicker substrate have been suggested as a way to moderately improve the bandwidth to 10-15%, at the expense of increasing the surface-waves which can result in a lower efficiency and a serious degradation of the radiation performance. For wider bandwidth application, microstrip travelling wave arrays have been used; these antennas usually require complicated feed structures and/or multi-layer geometries.

In this communication we propose a novel type of log periodic microstrip array (LPMA) which can result in a bandwidth of 50% or larger with a relatively simple single layer feed mechanism. The concept is based on a printed version of a log periodic dipole array (LPDA) design, which uses a scaling of the spatial dimensions of radiating elements in order to achieve broad band operation. The phase reversal in the excitation of adjacent elements is known to be critical in assuring impedance matching over the broad bandwidth of the array and an end fire pattern in the backward direction. In the case of an LPDA in free-space, this phase reversal is achieved by mechanical crisscrossing of a two wire transmission line feed. In LPMA, this phase requirement can be satisfied when the narrow radiating microstrips are series-fed by a microstrip transmission line with a zig-zag pattern nearly symmetrical to the array axis. For those elements near resonance, the opposite feed locations automatically provide a near 180^{0} phase-shift needed for adjacent elements, as evidenced in the current vs. charge distribution of a microstrip patch antenna.The non-resonating shorter front elements serve as nothing more than a reactively-loaded transmission line to the active region consisting of the resonating strips.

As a preliminary approach, a transmission line method is used to investigate the feasibility of the concept. It is found that by a suitable adjustment of the locations of the input and output ports of each narrow microstrip element in this series-fed LPMA, a very wide band performance can be realized. Numerical and experimental results will be presented to show the array's S-parameters variations versus frequency. Important aspects of the design of such an array will also be discussed. Future work is planned to include the use of a more accurate theoretical model for computer simulation as well as pattern and gain measurements of the array over its entire bandwidth. The latter is particularly important if the antenna is to be used for any practical wideband application.

Layered Tape Dielectrics for Microstrip Patch Antennas

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Abstract

A new class of mcirostrip patch antennas employing tape based dielectrics is investigated. The effects of layered dielectrics, antenna shape and feed location are studied. Theoretical models of the various configurations have been developed and comparison of the experimental and theoretical values are made. The antennas fabricated in this manner provide a lower profile as well as more conformable antenna than the conventional thin, etched PC-board based devices. The antennas described have similar electrical characteristics to their etched equivalents. The flexibility in dielectric configuration provides the potential for new degrees of freedom in design for performance of the tape based antennas.

This research was partially supported by U.S. Air Force Contract Number F08635-87-C-0460 and Army Research Office Grant DAAL03-89-G-0085.

DESIGN OF BROADBAND, CONFORMAL, SPIRAL MICROSTRIP ANTENNA

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The microstrip antenna is typically narrow-banded, generally with a bandwidth less than 10%. Earlier efforts to broadband the microstrip antenna by using spiral strips were unsuccessful (C. Wood, *IEE Microw., Optics and Acoust.*, 3, 5-13, 1979). In this paper, we show that a bandwidth of 4:1 to 6:1 can be reached for a spiral microstrip antenna.

The key to our success is to use low dielectric substrate, preferably of the permittivity of free space, and to place a lossy load on a ring outside the mode-1 radiation zone. Our analysis shows that the spiral modes are compatible with a ground plane parallel to the spiral. However, higher order spiral modes are generated as the dielectric constant increases.

Measured pattern and impedance data in the 2-12 GHz range for the microstrip antenna, which has a 3-inch diameter and a (styrofoam) substrate thickness of 0.3-inch, will be presented. This antenna is first mounted on an 18-inch-diameter ground plane and then conformally mounted on a cylindrical shell 14-inch long and 6-inch in radius.

The residual energy not radiated in the mode 1 radiation zone, which is usually useless, is absorbed by a ring of absorbing material 1/2-inch wide at the edge of the spiral structure. Without this dissipative loading, the residual power would be radiated in $m=-1, \pm 2$ modes and also at the truncated edge. Our measurements indicate that this antenna has a slightly higher gain, but a lower directivity, than those of a dissipatively-loaded cavity-backed planar spiral of 2.5-inch diameter. This indicates a higher efficiency than the dissipatively loaded spiral.

INPUT IMPEDANCE OF MICROSTRIP ANTENNA WITH TERMINATED TUNING STUB

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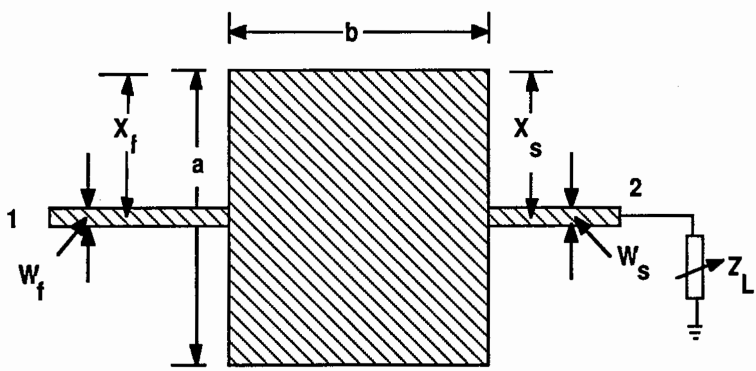
Tuning of microstrip antenna elements with a stub is widely used to control both resonant frequency and the input VSWR. Some experimental results using such stubs located at a specific position on the periphery were reported by Kerr J.L (Proc. Workshop on printedcircuit Antennas, New Mexico St. Univ., Oct 1979, pp.3.1-3.20). However these studies lack in theoretical analysis and have been conducted with open and short circuit terminations only. The present paper is intended to analyze and design a microstrip antenna with a stub located along its periphery (both radiating and non-radiating edges). The configuration is shown in Figure. The input impedance for this structure is calculated from the cavity model, treating the stub as another port attached to the antenna element.

Results on Input impedance, both R and X (Z=R+jX) will be presented for both open and short circuited stubs of different lengths. Also the case of doide mounting at the termination of the stub and its effect on the input impedance in ON and OFF states will be presented for diffrent lengths of the stub.

Factors underlying the choice of both length and the load termination of the stub for tuning the element for desired resonant frequency and VSWR will be discussed.



Configuration of Microstrip Antenna with stub tuning

ANALYSIS OF A PRINTED STRIP DIPOLE ANTENNA USED AS A HYPERTHERMIA APPLICATOR

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The noninvasive treatment of tumors by microwave hyperthermia depends on achieving effective penetration of electromagnetic energy into the body. Ideally one would like to focus the energy on the tumor without creating "hot spots" in other regions. The problem is that localized focusing requires high frequencies, whereas deep penetration in the highly lossy muscle tissue dictates low frequencies.

One way to focus the energy is to use an array of microstrip antennas. Microstrip structures are relatively inexpensive, easy to fabricate, light weight, and they can be made flexible enough to conform to nonplanar surfaces. These characteristics make microstrip antennas strong contenders as hyperthermia applicators. A number of authors have already investigated the use of rectangular and circular microstrip patch antennas for this purpose. A new applicator, the printed strip dipole antenna, will be discussed in this presentation.

Before studying the array problem, it is advantageous to investigate the performance of an individual antenna. Assuming that the tissue can be modeled as a layered medium, spectral domain techniques can be used to formulate an electric field integral equation for the unknown current distribution on the antenna. The method of moments can then be used to obtain an approximation to the current distribution. Once the current distribution has been obtained, the input impedance and the near-zone electric field distribution for the antenna can be found.

Since an analysis of this type requires a large amount of computer time, it is important to develop efficient numerical techniques. This work was carried out in a previous report (S.L. Dvorak and E.F. Kuester, *Scientific Report No. 94*, EM Lab., Dept. of Elec. and Comp. Eng., Univ. of CO, Boulder, CO 80309, 1989). It was shown in that report that a printed strip dipole applicator may produced "hot spots" because of the fringing fields at the ends of the antenna. In this presentation, methods to control these "hot spots" will be investigated. Also, variations in the input impedance due to changes in the tissue parameters and layer dimensions will be discussed.

RIGOROUS ANALYSIS OF SCATTERING FROM LARGE BUT FINITE ARRAYS - FREQUENCY SELECTIVE SURFACES AND MICROSTRIP PATCHES

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The analysis and design of arrays usually involves modeling the structure as being finite, if a small number of elements are involved, or infinite, if the number of elements is large enough such that truncation effects do not disturb the design. The structure may be a frequency selective surface, microstrip patch array or slotted waveguide array. The size of the finite array which can be modeled is usually limited by computation time or memory. If the array is large enough that an analysis is constrained by computation yet exhibits edge effects which are important as when sidelobe level information is necessary, or when the excitation field approaches grazing incidence, the infinite model is not useful. In this paper, a technique will be introduced which enables the efficient analysis of large arrays.

This technique does not use approximations based on locally planar models, or approximations of mutual coupling between elements or segments of elements of the array. A solution to the exact scattering formulation is found by exploiting the periodicity over the finite surface. The storage necessary to model the surface as well as the machine time needed to complete the solution is greatly reduced. An efficient and accurate solution to the scattering problem can therefore be found. The model can handle finite sized substrates supporting the array and is useful for all angles of incidence.

EXPERIMENTAL VERIFICATION OF THE THEORETICAL PREDICTION OF THE FAR FIELD CHARACTERISTICS OF PATCH RADIATORS

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Rapid progress in miniaturization of electronic equipment in recent years has resulted in a demand for smaller antennas. Consequently, the concept of creating antennas using microstrip technology emerged and has attracted increasing attention. However, in order to design a single radiating element, or an entire antenna, one should have available efficient methods for investigating the characteristics of the system as a function of its parameters. Obviously, far field patterns (FFP-s), in the prescribed band, are of great interest.

This paper reflects the work carried out to verify existing theoretical methods for prediction of the FFP-s of microstrip elements, or patches. It has been accomplished by calculating the patterns and comparing them with the corresponding experimental ones.

As the most appropriate model for verification, the rectangular patch with fundamental mode has been chosen. This canonical shape of the microstrip element has been repeatedly investigated and the results published. However, it became evident that surprisingly little attention is paid to FFP prediction, and only a few relevant papers have been found and taken into consideration. A number of S-band microstrip elements have been sketched, fabricated and matched. Then the FFP-s of both the theta and phi components of the field have been measured in amplitude and phase in cardinal and semicardinal planes. The corresponding patterns have also been calculated according to available theories. Finally, both sets of FFP-s have been thoroughly compared.

As a result, recommendations are made for the theoretical approach which should take precedence for the FFP calculation, and in what way the theoretical methods might be improved empiricaly to correspond better to experimental FFP-s. As a long term goal, measurements of the immediate field of the patch radiators have been initiated, in order to look into the structure of the electromagnetic field with the ultimate objective of better insight into the validity of theoretical models.

GAIN ENHANCEMENT OF MICROSTRIP LINE PLANAR ANTENNA

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Jian-Hui Shi Chong-Bin Yao

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There is a great deal of interest in the replacement of reflector antennas by low-cost planar antennas for receiving signals from data transmission and direct broadcasting TV satellites. A circularly polarized microstrip planar array formed by incorporated traveling-wave rampart lines for these applications has been reported (S.Nishimura , Y.Sugio and T.Makimoto , Proceedings of ISAP'85,Japan, 129-132,1985). Its antenna efficiency at 11.95 GHz is about 42%.In this paper, some gain enhancement techniques are suggested for improving the efficiency of such designs. One technique is to cover the planar antenna by using one or two layers of superstrates with proper spacings. The effective gain enhancement has been obtained and a little improvement of the impedance characteristics has been observed,forturnately. The second one is using a circularly polarized patch antenna instead of the common absorption load as the matching terminal for each traveling-wave linear array. The third technique is using some low-loss RF coaxial cables instead of the microstrip lines as the main corporated feedline. These RF cables are located on the backside of the antenna which have no coupling to the array and save the front space. The test results and analysis will be presented.

Monday AM
Joint AP-S, URSI-B Session 6
Transients

Chairs: Frederick M. Tesche, Consultant; David L. Moffatt, The Ohio State University
Room: W-102 *Time*: 8:15-12:00

ADVANCED VISUALIZATION METHODS FOR USE WITH FINITE-DIFFERENCE TIME-DOMAIN CODES

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As supercomputers become more accessible and as lower cost workstations approach the speeds of yesterday's large number-crunchers, there is increasing interest in and ability to do three-dimensional electromagnetic modeling. While these codes permit the analysis of realistic geometries, they present the user with a practical difficulty: an overwhelming amount of data. This is especially true in time-domain, partial differential equation based methods such as the finite-difference, time-domain (FDTD) technique. Because the primary unknowns in the FDTD method are the field variables **E** and **H**, this method provides complete vector field information throughout the entire computation volume at every time step in the simulation.

FDTD code users are usually reduced to looking at only a small fraction of the available data, *e.g.* 1-D plots of field strength vs. time at a few discrete points or total energy coupled into a region. A wealth of information is thrown away. Clearly, additional understanding of complex electromagnetic phenomena could be gained by the ability to visualize more of the computed results.

In an effort to gain access to this information, we have been developing some advanced graphics tools for examining FDTD results. The tools developed to date include a color/surface plotter for viewing data on 2-D slices through the computational volume and an iso-surface plotter for viewing 3-D surfaces of constant field strength. In addition, we have begun to investigate tools for visualizing volumetric data.

These codes are highly interactive and workstation based, the goal being ease of use. For added convenience, one of our workstations drives a computer-contolled videotape system. Thus, if facilities at the Symposium permit, a videotape will be shown which demonstrates our graphical capabilities.

MODELING PULSE DRIVEN MICROWAVE ANTENNA SYSTEMS AND BROAD BANDWIDTH PULSE SCATTERING FROM OBJECTS †

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We have developed a capability of modeling the performance of general, pulse driven, microwave antenna systems. Our approach is to use TSAR, a three-dimensional finite difference time domain (FDTD) code, to model the antenna structure and the surrounding near field environment. We then use FAR, a general purpose near-to-far field post-processor, to obtain its far-field response. Specifically, FAR utilizes the tangential electric and magnetic fields at a specified surface of the TSAR FDTD computational volume and calculates the resulting fields far from the equivalent magnetic and electric sources.

Analogously, we have used the TSAR-FAR approach to model the scattering of narrow and broad bandwidth pulses from a variety of scattering objects. The electromagnetic boundary condition $E_{scat} = -E_{inc}$ is used as a source term to drive the TSAR solver in a scattered, rather than a total, field mode. TSAR predicts the field near the scattering object, and FAR is then used to determine its far-field response. Information such as radar cross-section or pulse intensity distribution are immdeiately available.

The TSAR-FAR approach will be illustrated with a variety of problems. The source problems will include the far-field behavior of an array of pulse driven dipoles, a pulse driven waveguide, and a microwave feed horn. The scattering problems will include pulse scattering from spheres and plates with or without dielectric coatings. Comparisons with experimental results as well as with known analytical solutions will be made.

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† This work was performed by the Lawrence Livermore National Laboratory under the auspices of the U. S. Department of Energy under contract No. W-7405-ENG-48.

K-Pulse Waveforms For Dielectric Objects and Dielectric – Clad Metal Objects

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The Weierstrass factorization theorem suggests a product-type expansion for the K-pulse spectrum of an object in terms of its complex natural resonances treated as zeros. Such expansions are not useful for low Q objects such as a conducting sphere but can be used for high Q objects such as thin wires and thin wire loops. In this paper, product-type expansions are used to obtain the K-pulse waveforms of dielectric spheres and dielectric-clad metal spheres. K-pulse waveforms are also obtained for three dielectric disk objects utilizing measured multiple frequency scattering data. For the dielectric disk targets, the K-pulses are obtained using energy minimization procedures.

FD-TD VISUALIZATION OF ELECTROMAGNETIC WAVE INTERACTION WITH THREE-DIMENSIONAL OBJECTS

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Department of Electrical Engineering and Computer Science
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This presentation involves time-domain visualization of electromagnetic waves interacting with two different three-dimensional objects. It uses animation of various field components captured onto a VHS videotape, where shaded patches of color indicate the strength of the components. The fields are computed using the finite-difference time-domain (FD-TD) method, implemented on a Cray.

The first object is a trihedral corner reflector with an edge length of 5 λ_0. Incident upon this reflector are two 10 GHz tone bursts, at different angles. The videotape displays components of surface currents induced as each of the tone bursts reaches the reflector, and then dies off.

The second three-dimensional object is an engine inlet, encased in a radar absorbing material (RAM) covered box. This object spans 10 $\lambda_0 \times$ 10 $\lambda_0 \times$ 30 λ_0 at 10 GHz, which makes it one of the largest objects ever modeled with a fine level of detail. The videotape shows fields inside and outside the inlet building to the sinusoidal steady state, which is uniquely obvious on video.

Transient Response of a Random Ensemble of Small Scatterers: Independent Scattering Formulation

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The scattering of transient EM waveforms by an ensemble of identical small objects having random locations and orientations is considered. The objects are assumed to be described by their electric and magnetic dipole polarizabilities, and are taken to scatter independently (without mutual coupling). The locations and orientations of the objects are assumed to be statistically independent and identically distributed. It is found that the time-domain response is statistically nonstationary. We show that the scattered signal may be characterized by a mean field (a time function), and by an energy spectral density. To illustrate the analytical procedure we consider backscattering by a group of conducting spheres. The results indicate that for incident fields with short rise times the averaged scattered fields will contain prominent features corresponding to the leading response of the first object in the group and the trailing response of the last object in the group.

SOME OBSERVATIONS ON THE K-PULSE DURATION

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and

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The application of the K-pulse to radar target identification exploits the cancellation of the dominant target complex natural resonances by the K-pulse zeros. If the duration of the K-pulse for a target is smaller than its minimum value, not all of the dominant complex natural resonances can be stopped. Strictly speaking, in order for the K-pulse to be unique, the K-pulse must be of minimal duration. It is observed that minimal duration of the K-pulse is a necessary condition for its zero content to be minimum. From the targets considered, it is also observed that the K-pulse duration is more related to the density of the target's complex natural resonances in the complex plane than directly to the imaginary part of the target's most dominant complex natural resonances. Based on the density of the complex natural resonances of the target, a method for estimating the K-pulse duration is proposed.

Computation of Field Penetration into a Cavity using FD-TD

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The interest in Electromagnetic transient field penetration into complex structures has increased recently with the development of a few technologies. These developments include the use of advanced composite materials which provide less shielding than conventional metallic structures, the increased use of low level semiconductors for circuits, and the increasing use of cellular and wire-less LANS in building environments, etc.. While, in the former cases the field penetration is an undesirable situation, in the latter, one requires an enhanced and uniform field distribution within the structure. The Finite Difference-Time Domain (FD-TD) numerical technique has proven, with the advent of computer capabilities to be a practical method of solving both transient and steady-state scattering problems. In this method, developed originally by K. Yee(K.S. Yee, IEEE AP-14,302-307,1966), Maxwell's time-dependent curl equations are solved using finite differences, where the continuous electromagnetic field in a finite volume of space is sampled at distinct points in time. For open space problems, absorbing boundary conditions are used to terminate the computational domain.

In the present work the transient response inside a cavity is computed using the FD-TD technique in a 3-dimensional space. A super-absorbing boundary algorithm is used to terminate the FD-TD lattice. Transient plane waves are launched normally incident on a conducting cube with an open top. The magnitude of the field responses are computed at different locations inside the cube. Modifications to the cube geometry, either by adding lossy materials to the cube surfaces or by changing the size of the cube opening (aperture) modifies the field magnitudes inside the cube. The effect of these parameters on the field distribution, within and in the vicinity of the cube will be presented at the talk.

LATE-TIME CURRENT RESPONSE OF A CONDUCTING CYLINDER TO CYLINDRICAL ELECTROMAGNETIC WAVES

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An analytical study of the late-time currents induced on a perfectly conducting circular cylinder illuminated by a cylindrical electromagnetic wave generated by a parallel filament carrying a unit-step current has been carried out. A general analytical procedure consists in obtaining first the frequency domain solution to the problem under investigation and then using the inverse Laplace transform for deriving the time domain solution. The analysis is based on the frequency domain eigenfunction solution of the induced current density on the cylinder surface. The corresponding inverse Laplace transform is computed by closing the contour in the complex plane, approximating the branch cut contributions and adding the contributions due to the poles. Unlike the solution for the early-time response obtained by the authors in earlier papers, a single expression which is valid for both the shadow and illuminated regions is derived. The expression derived in this paper is different from that obtained earlier (J. Ma and I.R. Ciric, Proceedings of the 2nd International Symp. on Antenna and EM Theory, Shanghai, China, Aug. 29 - Sept. 1, 1989.), where the integrals corresponding to the branch cut contributions are evaluated numerically, while in this paper they are represented by analytical expressions which are derived by employing small argument approximations of the Hankel functions involved. Even though the results have been given explicitly for the case when the line current is a unit-step function, the response for the case of a general variation of the line current may be obtained by superposition. Since the early- and late-time results overlap for a small section in the shadow region, opposite to the location of the line source, the late-time results can be used to check the early-time results, and vice versa.

APPLICATION OF K-PULSE TO COMPLEX NATURAL RESONANT FREQUENCY EXTRACTION

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and

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The estimation of the K-pulse from the impulse response of the target was given in an earlier work by Fok et. al. (IEEE AP-S, AP-35, No.8, pp. 926-934). The complex natural resonant frequencies of the target are extracted from the K-pulse as a by-product. This paper is concentrated on the estimation of the complex natural resonant frequencies through the K-pulse concept. The analysis is applicable both in time and frequency domain. The method is still based on the minimization of the energy contribution of the complex natural resonant frequencies in the late time. Sub-domain basis functions are used to represent the continuous part of the K-pulse model instead of using impulsive functions. This eliminates the necessity of interpolation and also reduces the number of unknowns. The solution is calculated through a matrix equation instead of iterative search. This further reduces the computation time spent on searching. For the targets considered, the estimated complex natural resonant frequencies compare well with the actual values.

Monday AM
URSI-B Session 9
Electromagnetic Scattering

Chairs: Hassan A. Kalhor, State University of New York; Arthur D. Yaghjian, Department of the Air Force

Room: W-108 *Time*: 8:15-12:00

SCATTERING FROM A DOUBLE-STRIP GRATING

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An exact solution for the problem of TE or TM plane-wave scattering from a periodic planar double-strip grating is formulated. The strip grating is assumed to be perfectly conductive and infinite in length, with two different strips within a unit cell. The formulation is based on a singular integral equation technique which was previously developed for the single strip grating (M. Guglielmi and H. Hochstadt, IEEE Trans. MTT, Vol. 37, pp. 902 - 909, May 1989).

The singular integral equation technique is based on a rigorous network formulation of a periodic strip grating structure, which was previously developed (M. Guglielmi and A. A. Oliner, IEEE Trans. MTT, Vol. 37, pp. 534-541, March 1989). In this formulation the strip grating may be represented either with an impedance network or an admittance network, depending on whether an aperture formulation or an obstacle formulation is used. In the aperture formulation the electric field in the aperture between the strips is used as the unknown, while the current on the strips is the unknown in the obstacle formulation. In either case, a key step in the formulation is the introduction of static wave impedances into the integral equations for the field or current. This results in an infinite set of decoupled integral equations which are frequency independent, but which rigorously describe the grating at any frequency. For the two cases of TM incidence and obstacle formulation, or TE incidence and aperture formulation, the decoupled static integral equations may be solved exactly with the singular integral equation technique. Hence an exact solution is obtained for both polarizations. The solution of the static integral equations is then used to develop exact expressions for the impedance or admittance parameters of the equivalent network which describes the grating. Once the equivalent network is obtained, a calculation of scattering from the grating is straightforward.

Results for scattering from the double-strip grating will be presented and compared with the single-strip case. In addition, as an independent verification of the exact solution, scattering results obtained from a purely numerical moment-method solution of the double-strip case will be presented and compared.

MODIFYING THE SCATTERING BEHAVIOR OF CONDUCTING TARGETS BY STRIP LOADING

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It is well known that the periodic conducting surfaces (gratings) exhibit strong frequency pependent scattering behavior. In other words for a monochromatic incident wave, one can obtain scattered fields of any desired distribution by proper choice of the grating period and the spacing between its elements. This idea can be used to advantage in modifying the scattering behavior of conducting targets. A plane conducting surface generates a large specular reflection which can be easily used for target detection. By loading the conducting surface with conducting strips supported on a dielectric substrate, the overall scattering behavior can be changed as desired.

To demonstrate this principle, we analyze the scattering of a plane wave by a plane conducting surface which is loaded by conducting strips on a dielectric substrate. The incident wave is assumed to be E-polarized. The structure can be of finite or infinite length in the direction of its periodicity. For the infinite problem the periodicity is used to reduce the problem to the consideration of one period only. For both the infinite and the finite problem the appropriate two dimensional Green's function is used to formulate the problem into a integral equation for the induced current. The current is determined and then used to calculate the scattered fields.

Computed results will be presented, and it will be shown that by proper choice of the structure parameters such as the period, strip spacing and the thickness of the substrate, the power in the specularly reflected wave can be reduced to very low levels which are very difficult to detect.

ELECTROMAGNETIC SCATTERING BY AND TRANSSMISION THROUGH A DIELECTRIC GRATING

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The problem considered here is to calculate the electromagnetic scattering from a two dimensional structure consisting of the following:

i) A dielectric layer with periodically varying dielectric constant, above a dielectric half-space as shown in Fig.1.

ii) Dielectric cylinders having dielectric constant (ϵ_1) in Fig.1, are replaced by conducting cylinders.

The system is excited by a plane wave, and both normal incidence and oblique incidence are considered. Both the transverse electric (TE) and transverse magnetic (TM) cases are treaed. The equivalence priciple is used to replace the cylinders by equivalent electric and magnetic currents. Two different sets of coupled integral equations involving the surface current are obtained by enforcing the boundary conditions on the tangential components of the total electric and magnetic field. The method of moments is applied to solve the integral equations. Simple expansion and testing function are used. In order to overcome the slow convergence of the solution, an averaging technique is employed.

A general program is written for the problem, and numerical results are obtained for the problem with different parameters.

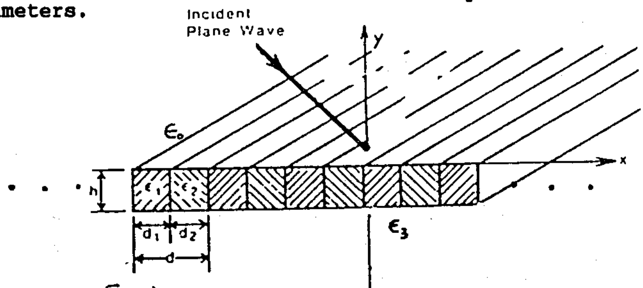

Fig. 1

BODY OF REVOLUTION CODE FOR THE MAGNETIC DUAL-SURFACE INTEGRAL EQUATION

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Conventional electric and magnetic-field integral equations for perfectly conducting bodies introduce spurious resonances at the resonant frequencies of the interior cavity formed by the scattering surface, and thereby yield unreliable results for bodies larger than about a wavelength across. The spurious resonances can be eliminated from either the electric or magnetic-field integral equation alone by using the corresponding dual-surface integral equation (Yaghjian, *URSI Digest*, Boulder, CO, 9, 1987). The general electric and magnetic dual-surface integral equations can be written:

$$\hat{n} \times \vec{E}_0(\vec{r}) = \frac{\hat{n}}{i\omega\epsilon_0} \times \oint_S \left[k^2 \vec{K}\psi_o - \left(\nabla'_S \cdot \vec{K}\right) \nabla'\psi_0\right] dS', \tag{1}$$

$$\hat{n} \times \vec{H}_0(\vec{r}) = \frac{1}{2}\vec{K}(\vec{r}) - \hat{n} \times \oint_S \vec{K} \times \nabla'\psi_0 dS', \tag{2}$$

where $\vec{E}_0, \vec{H}_0$ and ψ_0 are defined as

$$\vec{E}_0(\vec{r}) \equiv \vec{E}_{inc}(\vec{r}) + \alpha \vec{E}_{inc}(\vec{r} - \delta\hat{n}),$$

$$\vec{H}_0(\vec{r}) \equiv \vec{H}_{inc}(\vec{r}) + \alpha \vec{H}_{inc}(\vec{r} - \delta\hat{n}),$$

$$\psi_0(\vec{r}, \vec{r}\,') \equiv \psi(\vec{r}, \vec{r}\,') + \alpha\psi(\vec{r} - \delta\hat{n}, \vec{r}\,'), \qquad \psi(\vec{r}, \vec{r}\,') = \frac{e^{ik|\vec{r} - \vec{r}\,'|}}{4\pi|\vec{r} - \vec{r}\,'|}$$

These dual-surface integral equations, (1) and (2), although identical in form and comparable in complexity to the original integral equations, provide a unique solution for the surface current $\vec{K}$ at all frequencies as long as the constant α has an imaginary part and the positive real constant δ is less than $\lambda/2$. A computer program to compute the electromagnetic scattering from bodies of revolution using the magnetic dual-surface integral equation (2) has been developed. The program uses the formulation of Mautz and Harrington (*Appl. Sci. Res.*, 20, 405-435, 1969) to solve the electric and magnetic-integral equations for bodies of revolution. The numerical results obtained for the sphere from the body of revolution program using the magnetic dual-surface integral equation are compared to the exact Mie solution. The computational time required to solve the magnetic dual-surface integral equation using Guassian elimination and the conjugate-gradient method will also be compared.

SCATTERING THEOREMS WITH ANISOTROPIC SURFACE BOUNDARY CONDITIONS FOR BODIES OF REVOLUTION

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V. H. Weston proved in 1963 two theorems for isotropic absorbing objects when they have certain rotational symmetry ("Theory of Absorbers in Scattering," IEEE Trans. on Antennas and Propagat., pp. 578-584, September 1963). These two theorems have been very useful for checking against numerical codes and for certain design applications. Recently we have found it necessary to extend the Weston's theorems to the case of anisotropic surface impedance boundary conditions. In this paper we show how the Weston's theorems can be generalized to include anisotropic boundary conditions and give proofs of two theorems which should be of use for validating the results of numerical electromagnetic codes. Theorem 1 shows the scattered field patterns for a "H-pol" incident plane wave and for a "V-pol" incident plane wave are identical when the surface impedance tensor satisfies a given relation. Theorem 2 will state that the backscattered field in the axial direction for a body of revolution (BOR) will be zero when the condition of Theorem 1 is met. Numerical calculation is performed to demonstrate the validity of the theorems presented in this paper for various types of bodies of revolution.

DERIVATION AND UNIQUENESS OF SOLUTION OF DUAL-SURFACE INTEGRAL EQUATIONS

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Magnetic-field surface integral equations for perfect conductors appeared in the literature as early as 1931 (Murray, Am. J. Math., p.275), and both electric and magnetic-field surface integral equations were derived in Maue's definitive 1949 Zeitschrift Fuer Physik paper. However, only in the last ten years or so have digital computers become fast enough to solve these surface integral equations for arbitrarily shaped, 3-D, multi-wavelength bodies.

Unfortunately, as Murray and Maue noted, the original electric and magnetic-field integral equations (EFIE and MFIE) fail to produce a unique exterior solution at frequencies equal to the resonant frequencies of the corresponding interior cavity. Since the density of cavity resonant frequencies increases rapidly beyond the first resonant frequency, which occurs when the dimension of a full-bodied 3-D scatterer equals about one wavelength, the numerical solution of 3-D, multi-wavelength bodies is severely hampered by these spurious resonances.

Among the alternatives that have been proposed for eliminating the spurious solutions from the original integral equations, the combined-field or combined-source integral equation, and the augmented electric or magnetic-field integral equation appear the more generally applicable and effective in numerical practice. However, for arbitrarily shaped, 3-D, multi-wavelength bodies, the combined and augmented integral equations also have their drawbacks. The combined-field and combined-source equations involve the operators of both the magnetic-field equation and the electric-field equation, which takes considerably more programming ingenuity and computer time than the original MFIE to achieve the same accuracy of solution. The augmented MFIE involves only the magnetic-field operator, but the augmented integral equations require a special procedure to eliminate all the spurious solutions from bodies of revolution.

Herein, we derive dual-surface electric and magnetic-field integral equations that differ only slightly and eliminate all the spurious solutions from the original electric and magnetic-field integral equations. The derivation of the dual-surface equations requires the introduction of a fixed second surface interior and parallel to the surface of the scatterer, but the resulting integral equations are applied to the single surface of the scatterer. We prove that they produce a unique solution at all real frequencies, and demonstrate their applicability to multi-wavelength bodies by solving the dual-surface magnetic-field integral equation for a rectangular scatterer using the method of conjugate gradients. The dual-surface magnetic-field integral equation is contained in a previous abstract (URSI Digest, Boulder CO, p.9, 1987), but the derivation and proof of uniqueness of the dual-surface magnetic and electric-field integral equations will be presented for the first time.

ELECTROMAGNETIC SCATTERING BY A CONDUCTING TWO-DIMENSIONAL WEDGE WITH FINITE FACES

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Abstract

An analytical solution is described for the problem of scattering by a conducting cylindrical wedge with finite faces. The scattering solution is obtained for and E- and H-polarizations.

The scattering problem is formulated as a set of dual integral equations involving solutions of the scalar wave equation in cylindrical coordinates expressed in terms of the Kontorovich-Lebedev integral transform. The solution of these equations is obtained using a method developed by Lebedev and Skal'skaya (Applied Mathematics and Mechanics, 38, 1033-40, 1974) in which the unknown function is expressed in quadratures, using auxiliary functions satisfying Fredholm integral equations of the second kind with a symmetric kernel.

The analytical solution is used to obtain diffraction coefficients for the finite wedge for both polarizations. The multiple scattering contributions arising from interactions between the apex of the wedge and the ends of the faces may also be derived from the analytical form of the solution. The latter permits derivation of an expression for the current on the faces, from which the first order and higher order (e.g., traveling wave) contributions may be determined.

TE Scattering by a Two Dimensional Groove in a Ground Plane Using Higher Order Boundary Conditions

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University of Michigan
Ann Arbor, Michigan

Higher order boundary conditions involve derivatives of the fields beyond the first and were recently shown to be more effective than traditional first order conditions in modeling dielectric coatings and layers. In this paper we present an application of a third order generalized boundary condition to scattering by a filled rectangular groove . Deficiencies of such higher order boundary conditions are addressed and a correction is proposed for the present case. As part of the process of examining and correcting the accuracy of the proposed generalized boundary conditions an exact solution is developed and a comparison is provided with a solution based on the standard impedance boundary condition.

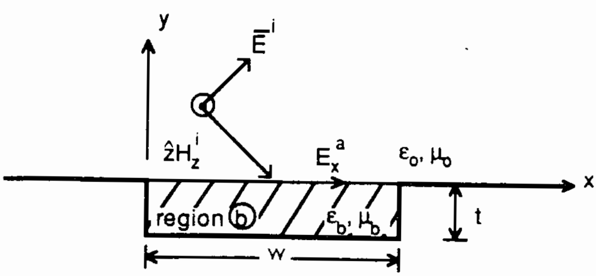

Fig. 1. Geometry of the rectangular groove in a ground plane

A SERIES REPRESENTATION OF THE FIELD SCATTERED FROM AN IMPEDANCE WEDGE

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An exact solution for the scattering by a wedge with impedance faces, illuminated by a plane wave perpendicularly incident on its edge has been obtained by Maliuzhinets. He gave a Sommerfeld spectral integral representation for the total field. Different asymptotic procedures have been adopted to derive high-frequency expressions from the above exact integral representation. It is well-know that these expressions yield very accurate results when the observation point is at least few wavelengths removed form the edge.

Based on a spectral interpretation of the integrand, an exact series expansion for the total field is obtained in terms of cylindrical wave functions, for an exterior $n\pi$ wedge angle when n is a rational number. This series representation is used to investigate the behaviour of the field in the immediate vicinity of the edge. Also, it allows to determine when a ray field regime is established, including the surface wave excitation mechanism.

Numerical results for an impedance right angled wedge are presented in order both to estimate the rate of convergence of the series and to analyze how the accuracy of a UTD solution decreases as the field point approaches the edge.

ON THE VARIANCES OF LOG-AMPLITUDE AND PHASE SCINTILLATIONS AT MILLIMETRE WAVE FREQUENCIES FOR PLANE AND SPHERICAL WAVE CASES

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The variances of log-amplitude and phase scintillations in a turbulent atmosphere have been discussed in the literature for the non-absorptive region.(TATARSKII, Springfield, 1971). However, for the absorptive region, the strong dependence of the variances on the outer scale of turbulence, Lo, makes it difficult to obtain a close expression for the variances. If we assume the Von Karmann model on the input region of the turbulence spectrum, the mathematical difficulties can be avoided and a closed expression can be obtained.

On both, plane and spherical wave cases, the variances of log-amplitude and phase fluctuations can be divided into three terms each one related with the mechanism which is responsible for the scintillation: scattering, absorption and the mixed effect. From the structure function obtained for the scintillations of both plane and spherical wave cases, (SIQUEIRA and COLE, to be published) the terms can be related with the filter functions defined for each one of the cases and the integrals can be worked out producing the expression for the variances.

The effect of absorption on the variances is very important since it makes the main contribution for the total value of the variance. Since absorption is relevant in the low frequency region of the spectrum, it is this part that will determine the variance of the fluctuation. The expressions for the variances were compared with experiments and the agreement was relatively good.

$$\sigma^2_{\chi,pl} = \left[0.308C^2_{nR} + 0.782(kL_o^2/L)^{5/6}C^2_{nI} - 1.14C_{nRI}\right]k^{7/6}L^{11/6}$$

$$\sigma^2_{S,pl} = \left[0.782(kL_o^2/L)^{5/6}C^2_{nR} + 0.308C^2_{nI} + 1.14C_{nRI}\right]k^{7/6}L^{11/6}$$

$$\sigma^2_{\chi,sph} = \left[0.124C^2_{nR} + 0.782(kL_o^2/L)^{5/6}C^2_{nI} - 0.463C_{nRI}\right]k^{7/6}L^{11/6}$$

$$\sigma^2_{S,sph} = \left[0.782(kL_o^2/L)^{5/6}C^2_{nR} + 0.124C^2_{nI} + 0.463C_{nRI}\right]k^{7/6}L^{11/6}$$

Monday AM

Joint AP-S, URSI-B Session 12

Microwave Imaging and Holography

Chairs: Jonathan D. Young, The Ohio State University; G. T. Poulton, CSIRO Division of Radiophysics

Room: W-110 *Time*: 8:15-11:40

FD-TD Modeling of Optical Holography

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This paper will describe the use of the finite-difference time-domain (FD-TD) solution of Maxwell's equations to compute a two-dimensional hologram of diffraction-limited objects.

Most computer generated holograms use Fourier transform algorithms, ray tracing, or wave optics. These methods may impose restrictions on the complexity of objects modeled or on the types of holograms. In addition they may not provide an accurate representation of the physics involved, especially when the size of the object is on the order of a wavelength of light. Our approach is to use the FD-TD method to model the holographic process in detail.

We report the computation of holograms for the following two-dimensional, dielectric and conducting canonical objects:

1. circular cylinder
2. rectangular cylinder
3. pairs of circular and rectangular cylinders.

The recording setup (the object and coherent light beams) are modeled in an FD-TD grid in two dimensions. The interference pattern of the reference and scattered object beams are computed in the far field at the locus of the surface of a holographic recording plate. The resulting electric field phase and magnitude data are used to assign electrical and physical properties to a recording medium in order to computationally transform it into a processed holographic plate.

This computed holographic plate is subsequently used as a scatterer in a second FD-TD grid. When illuminated with an incident reference wave, the scattered field from this plate reconstructs the image of the original cylinder or cylinders. Scattering patterns from the holographic reconstruction and from the original object are compared.

A STUDY OF SCATTERING FROM EDGE WAVES USING HIGH RESOLUTION RADAR IMAGES

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An "Edge Wave" describes a scattering feature of a target due to energy which attaches at a tip, propagates along an edge, and then re-scatters at another tip. The range-doppler behavior of edge wave scattering does not agree with the simple physical optics assumptions inherent in normal SAR or ISAR imaging. Thus, edge wave scattering, when visible, creates "artifacts", features which appear to be outside of the boundaries of the scatterer.

The behavior of this phenomenon has been studied using diagnostic ISAR imaging with a much larger coherent data window span (2–18 GHz and 90° + 180° azimuth angle) than conventional images. Processing of the data provides polarimetric edge wave scattering signature behavior. Information on where the edge wave echos must appear in an image, and how they may be distinguished from normal scattering centers is presented. The behavior will be illustrated with images from several simple scattering shapes.

URSI/B-3

MICROWAVE TOMOGRAPHY IMAGING FOR DIELECTRIC BODIES

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Beijing Institute of Technology

ABSTRACT

The Microwave Tomography Imaging(MTI) is a process that reconstruct the internal structure/characteristics of dielectric bodies using the advanced technique of microwave as detecting source. Because long-wavelength diagnostic imaging have a tomographic capability with high resolution not only medical applications but also many other nondestructive testing applications will emerge. The inverse EM scattering theory is applied to the MTI for the internal characteristics of dielectric bodies. The novel method shown here is that infer the equivalent current distribution of dielectric bodies from the measurement of forward scattered field owing to a non-plane wave incident upon the object, and then obtain the image of its internal structure. Thus, this technique, solved some limitation in some kinds of microwave imaging previously, is suited to the MTI of non-planar illuminating wavefront and non-weak scatterer. A system operating over the X-band microwave frequwncy range is described and some new results for test dielectric bodies in air are given.

THE RECOVERY OF PANEL ERRORS FROM MICROWAVE HOLOGRAPHIC DATA

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Microwave holography is now a well-established technique for the metrology of large reflectors. However, it suffers from the disadvantage that the resulting surface error map is spatially band-limited, so that fine detail of the surface structure of an antenna may require measurement of the far-field radiation pattern out to large angles from boresight. As well as taking significantly more measurement time, this can put severe constraints on the dynamic range required of the measurement system.

Most large reflectors are constructed of panels, and if the panels are rigid then surface errors take the form of panel misalignment. A misaligned reflector of this type will have errors with high spatial frequencies because of panel discontinuities, and low resolution holographic measurements can lead to incorrect assessment of panel positions in such cases.

Significant improvement can be obtained by recognizing at the outset that the reflector surface is composed of panels, and making use of a data reduction algorithm that allows such prior knowledge to be readily included. The Method of Successive Projections is such an algorithm, and this paper will demonstrate its application to panel position determination.

A NEW PROCEDURE FOR DETERMINING FOCAL POINTS OF LARGE DISTORTED REFLECTOR ANTENNAS

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Substantial errors can occur in predictions of the optimal feed position for a large reflector antenna if its surface has distortions or random deviations from its idealized figure. For paraboloidal reflector antennas, a conventional means for locating this desired position has used the assumption that the focal point of the antenna coincides with that of the "best fit" paraboloidal surface (M.R. Sullivan, NASA CR-3558, June, 1982). Measurements on a 15-meter diameter, mesh-reflector hoop-column antenna in a large near-field facility (L.C. Schroeder, et. al, NASA TM-4073, August, 1989) found deficiencies in this method of focal point location and required an experimental cut-and-try method for correct feed placement. This paper introduces a new procedure combining a version of weighted ray-tracing with optical path optimization and finds it superior to the "best-fit surface" method, in that it more closely predicts the actual focal point determined by experiment.

This new procedure begins with estimates of the local surface normals at a number of measured positions on the reflector surface. These normals are used to generate a set of (skew) ray directions that are grouped in all possible pairs. Midpoints of the lines of closest approach of each pair are then weighted by the products of the nominal strengths of the surface illumination at the corresponding measured surface positions. The set of all weighted midpoints then describes a focal zone volume whose centroid represents a first approximation for the actual focal point. Since the original surface normals were only estimates, this approximate point is refined as follows. A collection of optical paths is generated, equal in number to the number of measured surface points, each path proceeding separately from a datum aperture plane to the measured reflector surface points and then to the approximate focal point. Maximization of a sum of illumination-weighted phasors corresponding to this collection of optical paths then produces the final focal position estimate. The method and its performance on measured 15-meter antenna data are then described, along with implications for other antenna measurements.

INVESTIGATION OF BISTATIC EDGE SCATTERING VIA MONOSTATIC HIGH RESOLUTION POLARIZATION DIVERSITY MICROWAVE IMAGING

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This paper introduces a method for studying *bistatic* microwave polarimetry on a *monostatic* range. The method relies on

1. suitably positioned "microwave mirrors" and
2. the fact that high resolution microwave imaging may separate distinct monostatic and bistatic scattering centers.

The methods are exemplified for bistatic scattering by a straight edge. Thus we show

1. Kennaugh's and Huynen's characteristic operator theory applies to characterizing bistatic scattering centers;
2. predictions on the basis of the Uniform Geometrical Theory of Diffraction (UTD) compare well with experiment, as for frequency and aspect angle dependencies of the scattering centers.

DETERMINATION OF PARTICLE SIZE DISTRIBUTION USING A NEURAL NETWORK TRAINED WITH BACKSCATTER MEASUREMENTS

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Inverse techniques have been used for probing and identifying various properties of objects in different environments. Previously, inversion methods such as smoothing, statistical, and Backus-Gilbert have been used in investigating profiles of particle distributions. In this paper, we train a layered perceptron neural network to determine particle size distributions. A major advantage of this approach is that, once trained, the inverse problem of obtaining size distributions can be solved speedily and efficiently.

We consider the inverse problem of finding the particle size distribution from the measurements of backscattered light on an optically thin medium containing particles. The first-order scattering approximation is used. The particle size distribution $n(r)$ is the output of the neural network. The backscattering cross section of the medium $\beta(\lambda_i)$ measured at different wavelengths, λ_1, λ_2, λ_3, is the input data. We assume that $n(r)$ is governed by the log-normal size distribution so that it is characterized by two quantities: the mean size r_m and the standard deviation σ. The inverse problem becomes that of finding the output r_m and σ for given input $\beta(\lambda_i)$. The relation between $\beta(\lambda_i)$ and the parameters r_m and σ is nonlinear.

A multi-layer perceptron neural network trained with the backpropagation algorithm is used. The training data is provided by first considering the forward problem of calculating $\beta(\lambda_i)$ at different frequencies with known r_m, σ and particle refractive index. The refractive index is assumed to be 1.53-j0.008 and the wavelengths to be $\lambda_1 = 0.53$ µm, $\lambda_2 = 1.06$ µm and $\lambda_3 = 2.12$ µm. The mean size and standard deviation of the size distribution are chosen as $0.3 \leq r_m \leq 2.8$ and $1.25 \leq \sigma \leq 2.5$, respectively. A set of 320 data pairs containing r_m, σ and $\beta(\lambda_i)$ is used to train the network. Another set of 16 pairs of data is used to test the network by inputting $\beta(\lambda_i)$ and finding the outputs r_m and σ. It is shown that the neural network yields good results for the testing data with the percentage of error less than 10% for most of the testing input $\beta(\lambda_i)$.

Monday AM
Joint AP-S, URSI-B Session 13
Topics in Electromagnetics

Chairs: Ray J. King, Lawrence Livermore National Laboratory; R. D. Graglia, CESPA-Politecnico

Room: W-101 *Time:* 8:15-12:00

8:20	**Scattering by a Sphere Coated with Layered Chiral Materials and Jump-Immittance Sheets** R. D. Graglia, CESPA-Politecnico; P. L. E. Uslenghi*, The University of Illinois at Chicago; C. Long Yu, Pacific Missile Test Center	56
8:40	**The Efficiency of a Horizontal Electric Dipole in a Grounded Dielectric Slab with a Resistive Sheet Cover** R. C. Hall*, Ball Communication Systems Division	57
9:00	**A General Recursive Solution for the Analysis of Surface Waves in a Multilayered Dielectric Medium with Optional Impedance Sheets at the Layer Boundaries** Glen D. Hilderbrand*, Rockwell International Corporation; Robert D. Strattan, The University of Tulsa	58
9:20	**A Reciprocity Development of the Relationship Between Antenna Gain and Antenna Aperture** W. A. Davis*, Virginia Polytechnic Inst. & State Univ.	59
9:40	**Low Frequency Scattering from Cylindrical Structures at Oblique Incidence** K. Sarabandi*, The University of Michigan	60
10:00	**Coffee Break**	
10:20	**Spectral Domain Interative Solution of Microstrip Phased Arrays and Scatterers Using Green Functions and FFT** J. G. Cuevas*, Universidad Politecnica de Madrid	61
10:40	**Application of Generalized Impedance Boundary Conditions to Diffraction by a Multilayered Metal-Dielectric Junction** M. A. Ricoy, John L. Volakis*, The University of Michigan	62
11:00	**The Determination of Material Parameters Using a Surface Wave Technique** Jeffrey A. Berrie*, A. Dominek, The Ohio State University	63
11:20	**Scattering by a Composite Wedge: Moment Method/UTD Solution** A. J. Booysen*, C. W. I. Pistorius, University of Pretoria	64
11:40	**Analysis of Coupling Characteristics of Coplanar Waveguides and Microstrip Lines to Multi-Layer Dielectric Media** Magdy F. Iskander*, T. S. Lind, University of Utah	AP-S

SCATTERING BY A SPHERE COATED WITH LAYERED CHIRAL MATERIALS AND JUMP-IMMITTANCE SHEETS

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The scattering of a plane electromagnetic wave by a structure consisting of a metallic sphere coated by any number of layers of chiral materials is considered. The layers are separated by jump-immittance sheets, which allow for discontinuities in the tangential components of electric and/or magnetic fields. The boundary-value problem is solved exactly, and the inverses of matrices that appear in the chain-matrix algorithm are evaluated analytically.

A computer code is developed for the scattered far field and the bistatic radar cross-section. It is tested on a variety of structures and over a wide frequency band. The influence of chiral layers and jump-immittance sheets on the cross-section is discussed.

An asymptotic analysis is performed for the cases of one and two chiral layers. For backscattering, the far field is obtained in terms of reflected and creeping-wave contributions. The asymptotic results are compared to those obtained via the exact analytical-numerical solution.

THE EFFICIENCY OF A HORIZONTAL ELECTRIC DIPOLE IN A GROUNDED DIELECTRIC SLAB WITH A RESISTIVE SHEET COVER

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This paper addresses the efficiency of a horizontal electric dipole (HED) embedded in a grounded dielectric slab that has a thin, partially conducting cover layer. The radiation efficiency of the HED will be studied as a function of the height of the HED in the substrate, the substrate parameters and the conductivity of the cover layer. The ground plane, substrate and cover layer are all assumed to be infinite in extent and invariant in the transverse dimensions. The exact solution for the fields of the HED in the layered dielectric medium are found in the spectral domain via the magnetic and electric vector potential components (A_Z, F_Z) that are perpendicular to the interface in the two layers adjacent to the HED. The use of these two vector potential components simplifies the multilayer dielectric problem so that the boundary conditions involving other layers can be found via an equivalent transmission-line problem (N.K. Das and D.M. Pozar, MTT-35, pp. 326-335, Mar. 1987). The spherical wave far fields are then found using the method of steepest descent.

The conducting cover layer can often be well modelled using a jump or resistive boundary condition where the sheet is replaced by an infinitely thin layer characterized electrically by a constant resistivity. It is unclear, however, exactly when this is valid. Therefore, a comparison will be made between the solution that employs the resistive boundary condition and the exact solution that considers the true thickness and dielectric properties of the cover layer.

A GENERAL RECURSIVE SOLUTION FOR THE ANALYSIS OF SURFACE WAVES IN A MULTILAYERED DIELECTRIC MEDIUM WITH OPTIONAL IMPEDANCE SHEETS AT THE LAYER BOUNDARIES

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Dr. Robert D. Strattan, Senior Member IEEE
University of Tulsa
Tulsa, Oklahoma

This paper develops a general solution for characterizing surface wave propagation in a multilayered dielectric medium. The multilayered medium is assumed to be infinite in two directions; individual layers can have arbitrary thicknesses, and complex permittivity and permeability properties. An option for thin admittance sheets at the boundaries of each interface in the multilayered medium is also included. The general surface wave theory is valid for a plane linearly polarized wave of either TE or TM polarization. Boundary conditions for the solution include options for either a ground plane, free space, or open circuit termination on one side of the multilayered stack.

An iterative method (the method of rotating coordinates) is used to solve the trancendental surface wave equations. This solution yields surface wave attenuation for the stack, and relative electric and magnetic field values as a function of position within the stack. Complex power as a function of position is then calculated from the electric and magnetic field values. The relative power is used to determine how well the surface wave couples into the multilayered stack. Examples of the power distribution in a multilayered stack for both well coupled and poorly coupled cases are included to illustrate the effects of a surface wave absorber becoming capacitive at high frequencies.

Results of the general multilayered surface wave approach are validated with two other non-iterative surface wave solution methods. The first is a surface impedance approximation which yields valid results for materials whose index of refraction is >>1. Comparisons between the surface impedance approximation and the multilayered recursive method for several multilayer cases are included in the paper.

The second comparison approach is a Zenneck wave solution method, which is an exact solution for a semi-infinite medium having arbitrary complex permittivity and permeability. Comparisons between the Zenneck wave solution and the general multilayered surface wave method are illustrated for a semi-infinite lossy slab with complex permittivity and permeability.

A RECIPROCITY DEVELOPMENT OF THE RELATIONSHIP BETWEEN ANTENNA GAIN AND ANTENNA APERTURE

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Numerous authors have considered the development of the $\lambda^2/(4\pi)$ relationship between antenna gain and antenna aperture. This paper presents a new look at this problem using a reciprocity basis for the development. Though many authors take a somewhat similar approach, this paper will highlight several features which appear due to the process used, rather than develop these features in a separate manner. Initially, a set of problems will be presented for application of the reciprocity theorem.

Three problems are used in this development. Two problems use the actual antenna in the transmit and receive modes respectively. The remaining problem is an arbitrary infetesimal dipole in the far field of the antenna of interest, without the antenna present. These problems will be used to develop the open-circuit voltage at the terminals of the antenna of interest when used as a receiveing antenna. When the fields of the infetesimal dipole are incorporated into the reciprocity formula, the resultant open circuit voltage is found in terms of the effective length of the antenna.

The open circuit voltage may now be used in the circuit relationship for the received power to develop the effective aperture. The corresponding input impedance is required in this development and is related to the input power to the antenna when used as a transmitter. With such an observation, we develop the effective aperture to the include the effects of polarization and efficiency, in addition to the usual directive gain and wavelength. Thus we find a simple way of including all of the effects of the antenna system in one development rather than take the alternate route to treating each factor of the antenna as a separate entity.

The result of this paper will be a consise development of the basic relationships for the gain and aperture of an antenna, including the effects of efficiency and polarization directly.

LOW FREQUENCY SCATTERING FROM CYLINDRICAL STRUCTURES AT OBLIQUE INCIDENCE

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Classical Rayleigh scattering theory is extended to the case of a homogeneous dielectric cylinder of arbitrary cross section whose transverse dimensions are much smaller than the wavelength. By assuming that the surface fields can be approximated by those of the infinite cylinder, the far zone scattered field is expressed in terms of polarizability tensors whose properties are discussed. Numerical results are presented for circular, semicircular, triangular and square cylinders.

SPECTRAL DOMAIN ITERATIVE SOLUTION OF MICROSTRIP PHASED ARRAYS AND SCATTERERS USING GREEN FUNCTIONS AND FFT

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Periodic array model approach is usually the first step in the analysis of more realistic problems such as finite and/or conformal arrays. Periodic array model is specially suited when the excitation is uniform so that it can be directly applied to plane wave excitation (FSS, polarizers, radomes, etc.) or phased excitations (phased arrays).

An iterative technique involving the use of dielectric-slab Green function and FFT will be presented for the case of several phased arrays and periodic scatterers. Also comparison will be made between the rate of convergence of several iterative algorithms including CGM, CST and others.

Application of Generalized Impedance Boundary Conditions to Diffraction by a Multilayered Metal-Dielectric Junction

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Generalized impedance boundary conditions (GIBCs) are often employed to study the scattering properties of structures with dielectric/ferrite materials. However, these boundary conditions typically lead to nonunique solutions if the modeled structure contains an abrupt material discontinuity. Nevertheless, for certain cases it is possible to avoid this issue by formulating the problem in a suitable manner.

Herein we consider the problem of diffraction by a vertically inhomogeneous material slab recessed in a perfectly conducting ground plane as shown in figure 1. The problem is formulated and solved via the generalized scattering matrix formulation (GSMF) in conjunction with the dual integral equation approach. Two crucial tasks arise in the solution process: the factorization of certain Weiner-Hopf functions and the determination of the pertinent waveguide modes. These issue are addressed by employing a GIBC simulation of the slab as illustrated in figure 2. This enables a substantial simplification in the development of the pertinent diffraction coefficient. It is important to note that the result is unique by virtue of the employed model and formulation.

The details pertaining to the development of the model will be covered in the presentation and patterns will be presented for multilayer junctions which validate the model.

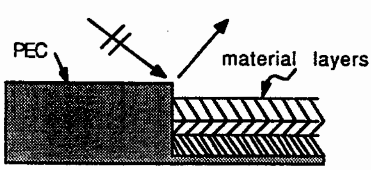

Figure 1. Original geometry.

Figure 2. Simulation model.

The Determination of Material Parameters Using a Surface Wave Technique

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Abstract

The determination of a material's electrical properties requires field measurements in the presence of a well defined geometry. The traditional techniques of measuring material samples in coaxial airlines or rectangular waveguides require the material to be appropriately shaped to completely fill the cross section of the fixture. However, not all samples permit this flexibility in shaping. Materials often have a planar sheet form which can be bonded to a substrate. A technique to acquire material parameters in this case uses the concept of surface wave coupling to a material coated, perfectly conducting substrate. The coating can consist of either a single uniform layer with an unknown constitutive parameter or as an unkown sheet resistance on a known bonded dielectric substrate. The required calibrated measurement is the electric field coupling between two probes. The unknown quantity is obtained through a Newton-Raphson search algorithm using the measured data and an analytical calculation. The algorithm is simplified when the probe separation distance is sufficient to allow the electric field coupling to be represented with a spreading cylindrical wave. In this case, the surface wave propagation constant is sufficient to determine the unknown quantity.

SCATTERING BY A COMPOSITE WEDGE : MOMENT METHOD/UTD SOLUTION

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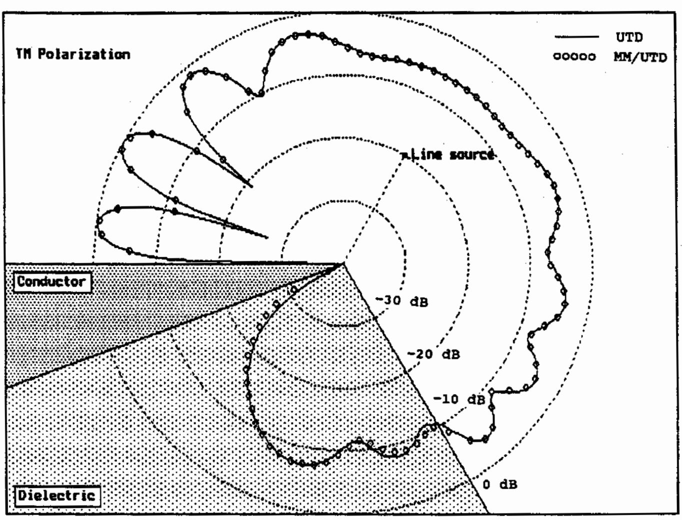
The electromagnetic scattering by an infinite two-dimensional wedge composed of conductor and dielectric is discussed. The scattered fields are computed by means of two methods, namely a uniform theory of diffraction (UTD) method and a numerical method which combines the moment method (MM) and the UTD.

To the authors' knowledge, no exact diffraction coefficients exist for scattering by a composite wedge. Existing UTD diffraction coefficients for a perfectly conducting wedge can however be modified to produce the composite wedge diffracted fields within acceptable accuracy. A hybrid MM/UTD method was developed to verify the accuracy of the modified coefficients. Details of both methods will be discussed, as well as restictions to the use of the modified diffraction coefficients.



Electric field around a composite wedge

Monday PM

URSI-B Session 14

Numerical Methods -II

Chairs: Atef Z. Elsherbeni, University of Mississippi; Ch. Hafner, Swiss Federal Institute of Technology

Room: W-107 *Time*: 1:15-5:00

COMPUTATIONS OF EM FIELDS INSIDE SENSITIVE SUBSECTIONS OF INHOMOGENEOUS BODIES WITH GMT

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The expansions used in the generalized multipole technique (GMT) are analytical solutions of the Maxwell's equations and are therefore well suited to expand the fields in any homogeneous 2D or 3D domain. Homogeneous bodies of any linear and isotropic material are very efficiently calculated with high accuracy over a wide frequency range. Examples have been shown in various papers. The advantages compared to other techniques are especially significant for lossy bodies with large volume to surface ratios.

Most realworld objects firstly have geometrically complex surfaces and secondly are inhomogeneous. The common approach of most techniques to compute these problems is to subdivide the inhomogeneous bodies into partially homogeneous domains. The uses of this are limited with GMT because the number of unknowns is rapidly increasing with the number of domains. On the other hand, field values are very often required only in the most sensitive parts of these bodies, but there with very high accuracy.

A special iteration routine for the MMP program package was developed and tested to solve these kinds of problems. The concept is simple but efficient: The coefficients of multipoles which have been calculated in the previous runs are included into the new simulation. This routine can be used for different purposes; to create any complex incident field sources; to improve and control a computation of a problem and to use the results of a simplified problem as a first step approximation for the next run. The present routine can include several levels of solutions of previous simulations with different symmetries into one simulation. A complex inhomogeneous body is therefore computed by starting with a much simplified body and then continuously increasing the complexity using all previous solutions. The approach is efficient even when many runs and discretisations must be performed because the matrices can be kept small and the accuracy can be well controlled. The applicability and limitations of this approach will be demonstrated and discussed in different examples.

CONTINUING PROGRESS IN PARALLEL COMPUTATIONAL ELECTROMAGNETICS

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Department of Electrical Engineering
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Recent progress on the development of fast and efficient methods of solving electromagnetic fields problems with the Connection Machine is reviewed. The suitability of low frequency matrix, high frequency PTD and time domain methods to the SIMD computational environment will be discussed from the point of view of recent experience.

Selected Connection Machine results for a large order Method of Moments matrix problem (N > 10,000), a high frequency PTD model calculation (up to one million facets) and time and frequency domain results from a well developed time domain solver will be presented and discussed relative to problems encountered and validity of the results. A short video tape illustrating these solutions will also be presented, including time domain scattering for a range of geometries, materials and incident waveforms .

GRAPHIC INPUT/OUTPUT PROGRAMS FOR THE 3D-MMP CODE ON PC'S

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The 3D-MMP code for numerical computations of electrodynamic problems is available on large and small machines like PC's. It is well known that for 3D problems large amounts of input data have to be handled. This causes very often errors in the models which are hard to find. Therefore, error checks and graphical representations of the geometric data are extremely important for 3D codes.

For MMP programs only the boundaries have to be discretized, which simplifies the modeling. On the other hand, the graphic capabilities of usual PC's are quite limited. To simplify the input, a modular concept has been applied. Complicated 3D bodies are constructed by superposition of several 3D parts which are generated from 2D objects by simple operations like translations and rotations. The 2D objects finally are compositions of lines and arcs. A large number of operations which act on these 2D and 3D objects make the modelling and modification of complicated 3D bodies even on PC's relatively fast and simple.

A speciality of the MMP programs is the necessity of giving the position of the multipoles to be used for the expansion of the fields. There are several simple geometric rules which allow to check whether a given multipole is useful or not. This allows to indicate ill posed multipoles graphically. In addition, multipoles can be generated automatically. For PC's a simple concept has been applied, which starts with automatic generation of multipoles for the 2D lines and arcs and allows the user to modify and check the multipoles either on the 2D or the 3D level of the modelling.

The MMP programs allow to compute the errors on the boundaries. Graphical plots of the error distribution on the boundaries and of course graphical editing of the data are important if it is necessary to improve the results.

Another important tool both for education and for validation of the results is the plot of field vectors, iso-lines, intensity etc. at least in 2D planes. In addition, the MMP graphic programs allow to generate and show films of both time-harmonic and periodic fields on PC's.

A NEW METHOD FOR COMPUTING THE MUTUAL INTERACTION OF ARBITRARY SCATTERING OBJECTS

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The exact mutual interaction among many objects can be characterized by a pair of first-order difference equations in spectral domain. This newly developed formulism assumes that the projections of these scatterers onto the z axis do not overlap, whereby the medium can be divided into slabs bounded by planes at $z = z_n$ such that the nth object lies entirely within the slab $z_{n-1} \leq z \leq z_n$. Each object can be a slice of a large object or a discrete object. It is characterized by a known dyadic scattering function $\mathbf{H}_n$ and interacts only with the wavefields that enter the slab containing the object. The scattering function for any two adjacent objects can then be computed from their individual scattering functions. For example, the mutual interaction between the first two objects alone can be calculated resulting in the two-object scattering function $\mathbf{H}_{1,2}$. Then the mutual interaction between this two-object aggregate and the third object alone can be solved resulting in the three-object scattering function $\mathbf{H}_{1,2,3}$. With this recursive algorithm, the exact mutual interaction among n objects can be obtained. The mutual interaction method (MIM) can be shown to offer at least a $2n^3/(n^2+n+2)$-fold computation-time advantage over the method of moments (MOM), assuming the worst case where each single-object scattering function is determined by MOM. This factor can be much higher ($\propto n^2$) with massively parallel computation. Numerical solutions will be presented for the problems of multiple scattering from two cylinders, one cylinder above a perfectly conducting plane, and one cylinder above a rough conducting surface.

PARALLEL MATRIX SOLVERS FOR MOMENT METHOD CODES USING TRANSPUTER ARRAYS

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A fundamental problem limiting the application of moment methods to radiation and scattering problems involving electromagnetically large objects is the computational requirements of the solution of the resulting set of linear equations. Parallel computing is attracting much attention as a computational methodology for addressing these problems. Preliminary work on extending the computational limitations on moment method codes using parallelism was reported last year (D.B.Davidson & J.H.Cloete, 1989 URSI Radio Science Meeting Digest p. 131). The algorithm was designed for an array of INMOS T800 transputers; the transputer has also been previously described (ibid).

The parallel conjugate gradient algorithm proposed (ibid) has now been implemented on an array of INMOS T800 transputers. A problem regarding the matrix transpose operation that originally required doubling the memory requirements has been solved and this solution will be reported. Crucial to parallel algorithms is the speed-up and efficiency obtained (speed-up is the ratio of time taken on one processor to time taken using N processors; efficiency is speed-up normalized by N). The actual speed-up and efficiency obtained as a function of problem and array size will be compared to the previously reported theoretical predictions.

Work on the suitability of parallel matrix solvers using direct methods, in particular Gaussian elimination, will also be reported. Iterative methods are often not very suitable for scattering problems requiring the solution of a large number of right hand sides.

RESONANCES OF A CURVED STRIP

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The natural frequencies or resonances of a curved strip are determined using two different techniques. The first technique considers the high–frequency interactions of the rays on the strip together with a resonance condition. The high–frequency contributions are found from GTD(Geometric Theory of Diffraction) as applied to the curved strip. These contributions include creeping waves and whispering gallery modes on the convex and concave side of the strip, respectively. Because of the strip's edges the contributions from these two species are coupled. The resonance condition is used to determine the natural frequencies.

The second technique uses a moment–method solution to the appropriate integral equation. An impedance matrix is calculated and the zeroes of the determinant of this matrix are the resonances of the strip. Some numerical results were presented previously(J.D. Kotulski, 1989 National Radio Science Meeting, Boulder) and these will be compared to the resonances determined using the high–frequency technique.

SCATTERING FROM N PARALLEL CIRCULAR DIELECTRIC CYLINDERS

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AHMED A. KISHK

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University of Mississippi, University, MS 38677

A rigorous solution to the problem of scattering from an arbitrary two dimensional array of infinitely long circular dielectric cylinders due to an incident electromagnetic wave is presented. The scattered field from each cylinder is expressed as a summation of cylindrical harmonic functions with unknown expansion coefficients. The expansion coefficients of the scattered field from each cylinder include the effect of all multiple interactions between the cylinders. To solve for the scattering coefficients, the scattered field from each cylinder is expressed in terms of the local coordinates of the other cylinders using the additional theorem of Hankel functions. Enforcing the continuity of the tangential components of the electric and magnetic fields on the surface of each cylinder yields an infinite set of equations. The set of equations is truncated properly and transformed into a matrix form which is solved numerically. The validity of the solution is verified by comparing the numerical results of specific cases with those obtained using an asymptotic technique. Various geometrical configurations of the parallel cylinders are considered with different electrical parameters.

ANALYSIS OF CONDUCTING STRIP RADIATORS ON GROUNDED DIELECTRIC SLABS BY MEANS OF THE MODIFIED DIAKOPTIC THEORY

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The modified diakoptic theory is applied to the problem of a antenna comprising a narrow conducting strip on a grounded dielectric slab. The antenna which may be straight or curved is fed by a slice generator at a specified location. Approximate open-port currents are determined for the diakopted antenna by an iterative technique based on a simple integral equation for current on short segments of the antenna, with the approximate current on each segment computed as if it were isolated from all other segments of the diakopted structure. The approximate open-port currents (converged) obtained from the iterative procedure are used in a variational expression for the elements of the open-port impedance matrix. The open-port currents and the open-port impedance matrix account for the presence of the grounded slab via Green's functions incorporating Sommerfeld integrals in the integral equations of the interation procedure and in the variational expression for the open-port impedance elements. Numerical results (open-port impedances and final currents) are presented for selected strip/slab configurations and parameters. For comparison, corresponding quantities are obtained from a MoM solution technique applied to the antenna. In addition, values of input admittance computed by the diakoptic theory, by the MoM, and determined from measurements are compared. Excellent agreement is observed in all cases. It is pointed out that in the modified diakoptic theory currents are obtained by solving a system of linear equations which is far smaller than is necessary in the MoM technique applied to the same problem.

TIME DOMAIN SCATTERING CALCULATIONS IN THE COULOMB GAUGE.

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ABSTRACT

The Lorentz gauge is the preferred gauge when problems in electromagnetic scattering and diffraction are solved by the classical approach involving a scalar potential ϕ and a vector potential $\mathbf{A}$. In this gauge

$$\nabla.\mathbf{A} + \frac{1}{c^2}\frac{\partial \phi}{\partial t} = 0.$$

For a perfectly conducting scatterer, the Electric Field Integral Equation (EFIE)

$$\left[\frac{\partial \mathbf{A}}{\partial t} + \nabla\phi\right]_{\tan} = \mathbf{E}^{inc}_{\tan}$$

then determines the surface currents $\mathbf{J}$ and surface charges ρ.

This formalism can be exploited to obtain an explicit time marching scheme in which the currents $\mathbf{J}^k$ and charges ρ^k at time step $k\Delta t$ are calculated from the currents and charges calculated at earlier time steps (and the exciting field). This scheme is *stable* only when $c\Delta t$ is chosen smaller than the minimum spatial separation of current sample points on the surface of the scatterer. In addition, for closed bodies, an averaging procedure must be used to suppress the growth of nonphysical oscillations corresponding to interior resonant cavity modes occurring at frequencies at which the frequency domain EFIE has nonunique solutions.

The question arises: are these features of stability and instability artefacts of the gauge condition, and can they be avoided by choice of another gauge? In this paper we obtain the free space vector and scalar potentials subject to the Coulomb gauge condition

$$\nabla.\mathbf{A} = 0.$$

We examine the time marching scheme derived by discretising the EFIE and the potentials thus obtained. The stability of this formulation both for open and closed scatterers is discussed, including numerical examples for flat plates and cubes. The relative merits of the Coulomb and Lorentz gauge formulation are identified.

FREQUENCY AND TIME DOMAIN ANALYSIS OF ELECTROMAGNETIC WAVE SCATTERING BY A THREE-DIMENSIONAL INDENTED OBJECT

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In the previous papers [H.Ikuno and L.B.Felsen, IEEE Trans., **AP-36**, p.1260, 1988; ibid p.1272], one of the authors has investigated the scattering of electromagnetic wave by a perfectly conducting two-dimensional object with concave-convex surfaces in both frequency and time domain, and has revealed some anomalous features which cannot be explained by applying conventional ray theory. There are, however, few researches about the scattering from three-dimentional non-convex objects [Proc. IEEE, 77(5), 1989].

Here, we analyze the scattering by the three-dimensional perfectly conducting indented object in frequency and time domain to reveal the scattering process of indented objects and the effect of the polarization on scattering properties. The frequency domain solutions can be calculated by the Yasuura method (mode-matching method) [K.Yasuura, Progress in Radio Science 1966-1969, **3**, p.257, 1971; H.Ikuno and K.Yasuura, IEEE Trans., **AP-21**, p.657, 1973; Radio Sci., **13**, p.937, 1978]. On the other hand, the time domain solutions are obtained from the frequency domain solutions by using the Fourier synthesis technique [E.M.Kennaugh and D.L.Moffatt, Proc. IEEE, **53**, p.893, 1965].

First, we calculate the scattering cross sections, transfer functions and scattering matrices of an indented body of revolution, and investigate the scattering characteristics in frequency domain. Using the Yasuura method, we get the scattering cross sections, transfer functions and scattering matrices within a specified accuracy : significant figures of the obtained data are at least three digits. We can find the interference effect on scattering cross-section of the indented body as well as the two-dimensional case. Second, to clarify the scattering process and the effect of the polarization on scattering characteristics, we calculate the TDG (Three-times Differentiated Gaussian) pulse responses by using the transfer function or the scattering matrix obtained above. We can clearly observe cross-polarization compornents [W.M.Boerner, IEEE Trans., **AP-34**, p.1395, 1986] for the indented object because of the deformation of scatterer surface.

Monday PM
URSI-B Session 19
Green's Functions

Chairs: R. J. Pogorzelski, TRW Space & Technology Group; R. D. Nevels, Texas A&M University

Room: W-102 *Time*: 1:15-5:00

ON THE NUMERICAL COMPUTATION OF A GREEN'S FUNCTION FOR HELICAL STRUCTURES

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TRW Space & Technology Group
One Space Park
Redondo Beach, CA 90278

In formulating integral equations for the electromagnetic behavior of helical structures such as helical antennas or twisted waveguides, one requires a Green's function representing the fields of a helical filament of current. A restricted form of such a Green's function is available in the literature. [D.A. Hill and J.R. Wait, IEEE Trans., MTT-28, 84-89, Feb. 1980] While in an earlier publication [J.R. Wait, IEEE Trans., MTT-24, 547-553, Sept. 1976] Wait suggested removal of the logarithmic singularity as a means of increasing the convergence rate of the series representing such a Green's function, he did not detail the procedure nor did he present data on the effectiveness of this suggested technique. As it stands, the series form presented in these publications is so poorly convergent as to be of very marginal utility in electromagnetic analysis. Moreover, the series involves products of modified Bessel functions which must be carefully handled because of their wide dynamic range. This also was not discussed in these earlier works.

This work concerns both the generation of the required special functions and effective acceleration of the series convergence. In accomplishing the former, more effective recurrence relations are derived for the modified Bessel functions augmented by appropriate exponential factors. By means of these relations the required functions may be computed without the numerical difficulties usually encountered. The series acceleration then follows quite naturally using asymptotic representations of the Bessel functions involving the same exponential factors to obtain approximate series which can be summed in closed form. The closed form summation technique involves summing a preliminary geometric series followed by integration of the result with respect to a parameter. The effectiveness as well as the details of the application and these techniques will be demonstrated.

Hertz Potential Method of Estimation of Cross Polarization In Simple Targets

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Abstract

The role of cross-polarization has become of great importance in modern target detection and identification schemes. The cross-pol is generated by discontinuities, randomness and roughness of the target . Hertz potentials to calculate fields is a pretty old technique. What we propose to do in this work is to obtain the Hertz scattering potentials for the electric and magnetic cases for simple radar targets like randomly oriented dipole, loop of wire and a cylinder. Hence, the scattered fields for all possible combinations of polarizations are derived. The electric and magnetic Hertz potentials are respectively given by:

$$\Pi^e = \frac{1}{4\pi(\sigma + i\varepsilon\omega)}\int_v \frac{exp(-\gamma R)}{R}\bar{J}dv \tag{1a}$$

$$\Pi^m = \frac{1}{4\pi i\mu\omega}\int_v \frac{exp(-\gamma R)}{R}\overline{M}dv \tag{1b}$$

The $\overline{E}^S$ and $\overline{H}^S$ are obtained from -

$$\overline{E}^S = (-\gamma^2 + \text{Grad Div})\,\Pi^e - i\mu\omega\,\text{Curl}\,\Pi^m \tag{2a}$$

$$\overline{H}^S = (-\gamma^2 + \text{Grad Div})\,\Pi^m + (\,\sigma + i\omega\varepsilon)\,\text{Curl}\,\Pi^e \tag{2b}$$

A computer code in Fortran IV has been prepared and being continuously upgraded to calculate the co- and cross polar properties of targets like an arbitrarily oriented dipole, an arbitrarily oriented loop of wire and a cylinder with all revelant parameters. It is found that the cross polarization ratio varies widely with observation angles in the azimuthal and elevation planes. An attempt is made to find the sector of angles which gives least cross-pol for monostatic and bistatic cases. It is observed at some particular orientation of the target, the cross-pol level may be even comparable to the co-pol scattered field.

NUMERICAL EVALUATION OF GREEN'S FUNCTIONS FOR ELECTRIC RING CURRENTS AND LOOP DIPOLES

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ABSTRACT. Spherical harmonic expansions are obtained for the vector electric and magnetic fields of sinusoidally varying time harmonic ring currents and loop dipoles. These infinite series involving spherical Bessel functions and associated Legendre polynomials can be summed directly for field point radial coordinate r sufficiently less than or sufficiently greater than the distributed source radius a. The iterated Shank's transformation is an efficient technique to accurately sum these slowly convergent series for values of r close to a. Several computational difficulties are encountered with the competing first order Kummer transform (subtraction and addition of the analytically summable principal asymptotic form of the summand). Although the use of higher order asymptotic expansions suggests an improvement in the performance of the Kummer transform, the demonstrable success and ease of application leads to the selection of the iterated Shank's algorithm for the present class of series. Utilization of these elementary fields or Green's functions is discussed in context of a synthesized plane wave in the near-field interior of a discrete set of sphere-mounted ring currents and loop dipoles.

SCATTERING BY OBSTACLES ALONG INTEGRATED DIELECTRIC WAVEGUIDE--AN APPROXIMATE QUANTIFICATION TECHNIQUE

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The motivation of this paper is to study wave scattering by obstacles along a practical integrated optical circuit, where a strip, a rib, or a channel guiding region is embedded in the layered substrate/film/cover environment. Knowledge of the electric Green's dyad for this particular structure is necessary to study scattering of surface waves by dielectric obstacles in the surround. However, this Green's dyad is not fully conceptualized and is difficult to quantify. Hence, an approximate solution is sought to solve this problem.

When a dielectric discontinuity having an index contrast $\delta n^2 = n_d^2(\vec{r}) - n_c^2$ is immersed in the cover layer, excess polarization current is excited and maintains a scattered field. This current is proportional to the product of the induced field and δn^2. Within the obstacle, the total field $\vec{E} = \vec{E}^i + \vec{E}^s$ consists of the impressed field of an incident wave augmented by the scattered field. Rearranging leads to the EFIE

$$\vec{E}(\vec{r}) - \int_V \frac{\delta n^2}{n_c^2} \left[\overline{\overline{G}}^p(\vec{r}|\vec{r}') + \overline{\overline{G}}^r(\vec{r}|\vec{r}') \right] \cdot \vec{E}(\vec{r}')\, dv' = \vec{E}^i(\vec{r})$$

where $\overline{\overline{G}}^p$ and $\overline{\overline{G}}^r$ are the principal and reflected electric Green's dyads respectively. The reflected Green's dyad $\overline{\overline{G}}^r = \overline{\overline{G}}_D^{\,r} + \overline{\overline{G}}_c^{\,r}$ consists of a discrete surface wave component augmented by a continuous radiative component. Since $\overline{\overline{G}}_D^{\,r}$ can be determined but $\overline{\overline{G}}_c^{\,r}$ is not quantified, we seek a sequential approximate solution. First, we make use of only the principal component of the Green's dyad. Second, we use the principal Green's function augmented by the discrete component of the Green's dyad. This method is applied to a simple structure (a planar dielectric waveguide) where the full Green's function is known.

The full solution is compared to the above approximations to ascertain their validity for various discontinuity configurations and spacings; the need for the inclusion of $\overline{\overline{G}}_D^{\,r}$ in this approximation will also be evaluated. It is anticipated that this approximation method will prove accurate for the simple planar waveguide structure, consequently establishing its potential validity for the practical integrated configuration.

ANALYSIS OF AN INFINITE PHASED ARRAY OF DIPOLE ELEMENTS WITH RAM COATING ON GROUND PLANE AND COVERED WITH LAYERED RADOME*

by

Ruey-Shi Chu

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Abstract

An analysis of an infinite array of dipole elements over a RAM (radar absorbing material) coating ground plane and covered with layered radome is presented in this paper. Radiation impedance of the dipole element is obtained when the array is in transmitting mode. Scattering analysis is carried out when the array is excited by an incoming plane wave and the dipole elements are terminated in loads. The electric field Green's function in terms of Floquet mode expansion due to a periodic δ-function horizontal dipole source is derived to satisfy the layered boundary conditions. Method of Moments is used to solve the current distribution on the dipole. Numerical calculation of radiation impedance of a dipole array covered with radome has been verified with the result of the waveguide simulator measurements. Numerical examples are given to show the effect of the RAM coated ground plane on the radiation impedance and the scattering characteristics.

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*This work was supported by Hughes Aircraft IR&D Project 1FA3.

SCALAR, VECTOR AND DYADIC GREEN'S FUNCTIONS FOR PROBLEMS OF PLANAR PERIODICITY

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Many electromagnetic problems are periodic in structure and in excitation on the x-y plane for a fixed z coordinate; phased arrays and frequency selective surfaces are well known examples. These problems have been solved by a mode matching method based on the expansion of fields in terms of Floquet modes.

Formulation of this class of problems by the method of Green's functions appear scanty and specialized [e. g., J. A. Kong, *Electromagnetic Wave Theory*, Wiley, 499-503, 1986]. In this paper, scalar, vector and dyadic Green's functions are presented for problems satisfying planar periodicity for source and geometry, which are met by infinite planar periodic structures such as phased arrays. By the method of eigenfunction expansion (in this case the scalar and vector Floquet mode functions), the scalar, vector, and dyadic Green's functions are derived.

These Green's functions are valid not only in a source-free region, as is in the literature (if they exist), but also in the source region. Thus they are readily applicable to field computations by the moment methods.

DYADIC GREEN'S FUNCTION FOR A BIAXIALLY ANISOTROPIC MEDIUM

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Department of Electrical and Computer Engineering
Syracuse University
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Although the subject of anisotropic media is a very old one, only a relatively small number of problems involving anisotropic media have been studied. Perhaps this may be due to limited interest, not to mention the excessive complication involved in the analysis of such problems. In recent years the industrial community has found several practical applications for anisotropic materials. Thus there is a great demand for electromagnetic engineers to solve many of the traditional problems in the anisotropic context. One well-established tool for solving electromagnetic scattering problems is Green's function. Derivation of Green's function for an anisotropic medium is the main content of this paper.

The medium under consideration is electrically anisotropic. In other words, the permittivity of the medium is a tensor of rank 2. Depending on the number of axes of symmetry the anisotropic medium is classified as uniaxial and biaxial. Lee and Kong (Electromagnetics, 3, 111-130, 1983) have considered a uniaxial medium and obtained its dyadic Green's function. We consider here the more general case of a biaxially anisotropic medium.

By definition the dyadic Green's function is the solution of the vector wave equation with a unit impulse source. We use the Fourier transform technique to solve this wave equation. We observe that there are two characteristic waves that can exist in this medium and they have distinctly different propagation constants. Both of these waves, because of their characteristic behavior, belong to the category of extraordinary waves. We derive the 'characteristic' field vectors to describe these waves and cast the solution to the wave equation in a dyadic form. With the availability of the dyadic Green's function, one can solve many problems of electromagnetic radiation and scattering from anisotropic media.

A COULOMB GAUGE ANALYSIS OF A WIRE SCATTERER

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Recently the Coulomb gauge has been presented as an alternative to the Lorentz gauge in mixed potential integral equation (MPIE) formulations for several two dimensional configurations (K.A. Michalski & R.D. Nevels, *IEEE Trans. Microwave Theory Tech.* 36, 1328-33, 1988; K.A. Michalski, R.D. Nevels & D. Zheng, *IEEE Trans. Antennas Propag.*, to appear April 1990). In each case the Green's functions are derived by the eigenfunction expansion technique. Several researchers have asked if there is a way to solve a Coulomb gauge problem avoiding advanced analysis methods and therefore suitable for presentation to beginning graduate students. This paper is a response to those requests.

We derive magnetic vector ($\bar{A}$) and scalar (Φ) potential Green's functions subject to the Coulomb ($\nabla \cdot \bar{A} = 0, \Phi \neq 0$) gauge for a general directed source in free space. It is shown that the Coulomb gauge vector potential Green's function can be extracted from the well known free space Lorentz gauge vector potential Green's function by taking advantage of a set of dyadic identities. This method avoids the difficulties associated with deriving dyadic Green's functions from first principles.

In order to confirm the correctness of our Coulomb gauge potential expressions we solve an electric field MPIE for the current on a straight finite length cylinder scatterer. The MPIE is solved by the method of moments. The numerically computed cylinder surface current and an equation for the scattered far field are presented and compared with those obtained with Lorentz gauge potentials. The potential expressions in the two gauges are compared in terms of numerical computation time and programming difficulty.

Surface Divergence of Magnetic Field

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Space divergence of magnetic field **B**, div **B** = 0, ie the sum of derivatives describing a change of **B** in space is always zero. When Maxwell described this mathematically (1864), the material world was considered to consist solely of indivisible atoms. Subsequently, electromagnetic field became *abstractly* defined as regions where corresponding forces can be detected. In Dec.1954 Einstein commented that matter was to be regarded itself as a part of electromagnetic field; but added there was no sufficient knowledge about electromagnetic filed (Einstein, The Meaning of Relativity, p. 82).

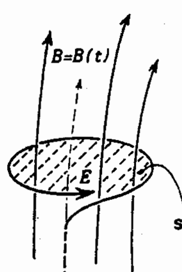
Annihilation of particles' shape provides understanding of EMF as part of matter. After annihilation of particles (e.g. $e^+e^- \rightarrow \gamma$) matter is released and spreads as FIELD waves throughout space until the waves die away and matter reaches the state of complete homogeneity generally called FIELD. The FIELD waves (e.g. gamma rays) are electromagnetic waves. Wavy FIELD has often been discussed in physics but never given the true recognition that, *wavy FIELD is EMF*. Consequently matter's condition of FIELD has not got the proper attention.

Since FIELD fills space in all directions and has no surface, it cannot appear in waves like waves on water surface. What are supposed as waves are actually FIELD vortexes, which are the only possible way of FIELD density change. In whirling condition FIELD exerts a strength **E** and by this strength the change can be described as curl **E**. The FIELD vortex is what it is called induced electric field **E**.

Initially vortex occurs in a plane and its effect arises on both sides of the vortex-plane. The bipolar region of FIELD in which FIELD-vortex exerts its effect is recognized as magnetic field **B**.

This qualitative understanding of electromagnetic fields as conditions of whirling FIELD can be quantitatively improved. Maxwell described that $\partial \mathbf{B}/\partial t$ corresponds to the induced electric field **E** by $-\partial \mathbf{B}/\partial t = \text{curl } \mathbf{E}$. The change $\partial \mathbf{B}/\partial t$ actually signifies that a flow of B-FIELD has to go out (or in) in the neighbourhood of the change. If the velocity of this flow is *c*, the total flow can be calculated by the divergence of (c **B**), div (c **B**). In particular, knowing that the change of **B** occurs through vortex, the divergence here is a surface divergence which as vector is written by capital D, Div (c **B**). Both vectors Div **B** and curl **E** are equals, describing the same change of FIELD from different points of view.

To illustrate the meaning of these descriptions, a region of **B**-FIELD is represented by four lines. After a period of time, the density of **B** in the region decreases. Now the **B**-FIELD should be shown by fewer lines, e.g. three. The actual amount of **B**-FIELD corresponding to the missing line (or lines), is the amount which has turned into vortex, now recognized as **E**-FIELD, as illustrated below.



$$-\partial \mathbf{B}/\partial t \quad = \quad c \text{ Div } \mathbf{B} \quad = \quad \text{curl } \mathbf{E}$$

$-\partial \mathbf{B}/\partial t$	c Div B	curl E
A macroscopic description of the change **B**=**B**(t)	A microscopic actual description of the change **B**=**B**(t)	Description of the change **B**=**B**(t) through vortex

surface divergence Div **B** (vector)

The existence of surface divergence Div **B** is evident for example, with a transformer, and it is important for understanding the real phenomenon of induction and EMF propagation.

TREATMENT OF HERTZ VECTOR IN THREE-DIMENSIONAL LATTICE NETWORK OF SPATIAL NETWORK METHOD

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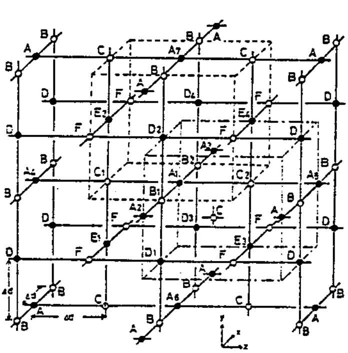
A Hertz vector defines a electromagnetic field expressed by a scalar and a vector potential in terms of a single vector function. I have proposed the Spatial Nework Method. **Fig. 1** shows a three-dimensional lattice network model of Maxwell's equation used in the method. In the network, each field variable and each component equation are assigned at each lattice point. Since each component equation satisfies the relation of rotation between field variables. This treatment can be expanded to other vector field functions formulated by the rotation operator. Already, I showed that the vector potential field can be expresssed in the network. In this presentation, I show that a Hertz vector field can be also expressed in the lattice network. The basic equations of the Hertz vector field is given as follows.

$$\nabla \times \Pi = -\mu_0 \frac{\partial \Pi^*}{\partial t} \qquad (1a)$$

$$\nabla \times \Pi^* = \varepsilon_0 \frac{\partial \Pi}{\partial t} \qquad (1b)$$

Here, Π and Π^* are the electric-type and the magnetic-type Hertz vectors. **Table 1** presents the correspondence of each component in the euation of the Hertz vector to each of the lattice points. The correspondence between variables of the Hertz vector and the equivalent circuit is also presented. These expressions can be performed without changing the structure of the network for Maxwell's equation. it can be proved that this network can satisfy the wave equation of the Hertz vector in the space and the time domin.



Electric Node			Magnetic Node		
	Composite Equation	Variables		Composite Equation	Variables
A.	$\frac{\partial \Pi_x^*}{\partial z} - \frac{\partial \Pi_z^*}{\partial x} = \varepsilon_0 \frac{\partial \Pi_y}{\partial t}$	$V_y = \Pi_y$	F.	$\frac{\partial \Pi_x}{\partial z} - \frac{\partial \Pi_z}{\partial x} = -\mu_0 \frac{\partial \Pi_y^*}{\partial t}$	$V_y^* = \Pi_y^*$
	$-\frac{\partial \Pi_y}{\partial z} = -\mu_0 \frac{\partial \Pi_x^*}{\partial t}$	$I_z = -\Pi_x^*$		$-\frac{\partial \Pi_y^*}{\partial z} = \varepsilon_0 \frac{\partial \Pi_x}{\partial t}$	$I_z^* = \Pi_x$
	$\frac{\partial \Pi_y}{\partial x} = -\mu_0 \frac{\partial \Pi_z^*}{\partial t}$	$I_x = \Pi_z^*$		$\frac{\partial \Pi_y^*}{\partial x} = \varepsilon_0 \frac{\partial \Pi_z}{\partial t}$	$I_x^* = -\Pi_z$
D.	$\frac{\partial \Pi_z^*}{\partial y} - \frac{\partial \Pi_y^*}{\partial z} = \varepsilon_0 \frac{\partial \Pi_x}{\partial t}$	$V_x = \Pi_x$	B.	$\frac{\partial \Pi_y}{\partial x} - \frac{\partial \Pi_x}{\partial y} = -\mu_0 \frac{\partial H_z}{\partial t}$	$V_z^* = \Pi_z^*$
	$\frac{\partial \Pi_x}{\partial z} = -\mu_0 \frac{\partial \Pi_y^*}{\partial t}$	$I_z = \Pi_y^*$		$\frac{\partial \Pi_z^*}{\partial y} = \varepsilon_0 \frac{\partial \Pi_x}{\partial t}$	$I_y^* = -\Pi_x$
	$-\frac{\partial \Pi_x}{\partial y} = -\mu_0 \frac{\partial \Pi_z^*}{\partial t}$	$I_y = -\Pi_z^*$		$-\frac{\partial \Pi_z^*}{\partial x} = \varepsilon_0 \frac{\partial \Pi_y}{\partial t}$	$I_x^* = \Pi_y$
E.	$\frac{\partial \Pi_y^*}{\partial x} - \frac{\partial \Pi_x^*}{\partial y} = \varepsilon_0 \frac{\partial \Pi_z}{\partial t}$	$V_z = -\Pi_z$	C.	$\frac{\partial \Pi_z}{\partial y} - \frac{\partial \Pi_y}{\partial z} = -\mu_0 \frac{\partial \Pi_x^*}{\partial t}$	$V_x^* = -\Pi_x^*$
	$\frac{\partial \Pi_z}{\partial y} = -\mu_0 \frac{\partial \Pi_x^*}{\partial t}$	$I_y = -\Pi_x$		$\frac{\partial \Pi_x^*}{\partial z} = \varepsilon_0 \frac{\partial \Pi_y}{\partial t}$	$I_z^* = \Pi_y$
	$-\frac{\partial E_z}{\partial x} = -\mu_0 \frac{\partial \Pi_y^*}{\partial t}$	$I_x = \Pi_y^*$		$-\frac{\partial \Pi_x^*}{\partial y} = \varepsilon_0 \frac{\partial \Pi_z}{\partial t}$	$I_y^* = -\Pi_z$

Fig. 1 3-D Lattice Network **Table 1 Correpondence at Lattice Points**

Monday PM

Joint AP-S, URSI-B Session 21

Antenna Analysis I

Chairs: Warren L. Stutzman, Virginia Polytechnic Inst. & State Univ.; T. G. Campbell, NASA Langley Research Center

Room: W-106 *Time*: 1:15-5:00

HF TRAILING WIRE ANTENNA INPUT IMPEDANCE STUDY

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Measured input impedance for a practical hf (3-30 MHz) trailing wire antenna, deployed from a KC-135 aircraft, is shown to be related to the theoretical input impedance computed by the NEC-PC numerical code through a bilinear transformation. A direct correspondence between computed and measured impedances may be developed even though the computer solution is based on an idealized feed model.

The input impedance of a 16.8 meter trailing wire antenna is measured at numerous frequencies between 3 and 30 MHz. The three complex constants which characterize the bilinear transformation are determined by comparing the measured to theoretical impedances. The comparison is made by finding the three constant values which minimize a suitably defined error for the overdetermined system of equations relating computed and measured impedance values.

Accurate prediction of input impedance for the practical antenna at new frequencies of interest becomes feasible because of the experimental characterization procedure.

Interactions Among Harmonically Related Vertical Antennas in the Mobile Environment

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There has been recent practical interest in the study of harmonically related vertical antennas, mounted within a wavelength or two of each other, on a ground plane of at most several wavelengths in extent. We discuss, both formally and numerically, the effect of interactions among these antennas, considering cases when one or more are simultaneously excited. We will also discuss the effect of placing an untuned vertical antanna terminated with a highly reactive termination within several wavelengths of the antennas.

We will compare our numerical results to a series of measurements performed using a set of $\lambda/4$ antennas at frequencies f, $1.5f$, $3f$, and $6f$. The additional vertical antenna will be either untuned or designed to be a loaded $\lambda/4$ at $.2f$. The measurements are made using several geometric configurations of the antennas in relation to a ground plane. Of particular interest will be the effect of changes in the termination on one antenna on the other antennas.

Monday PM
URSI-B Session 22
Rough Surface Scattering

Chairs: Gary S. Brown, Virginia Polytechnic Inst. & State Univ.; Ezekiel Bahar, University of Nebraska

Room: W-108 *Time*: 1:15-5:00

A SMALL PERTURBATION MODEL FOR SKEWED RANDOM SURFACE

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A small perturbation model including up to the third order surface height statistics is developed to account for the skewness effects in rough surface scattering. For a wind generated surface this extension enables us to distinguish the upwind and downwind directions from radar returns.

It is shown that in general the backscattering coefficient depends on both the surface roughness spectrum and the Fourier transform of its skewness function. Whereas the roughness spectrum is a centro-symmetric function, the Fourier transform of the skewness function is an odd function along any direction.

Through numerical calculations, it is found that the effect of skewness is the cause for difference in the backscattering coefficients between upwind and downwind directions. Comparisons between the current model and *in situ* measured data are provided for various wind speeds and incident angles.

NUMERICAL COMPARISON OF APPROXIMATE ROUGH SURFACE SCATTERING METHODS 2: RANDOM ROUGH SURFACES

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Scattering from random rough surfaces possesses important applications in many areas of science and engineering such as optics, oceanography, and remote sensing. Many approximate solutions for rough surface scattering have been suggested and utilized with various restrictions. Examples of these approximate methods are the small perturbation method, the tangential plane approximation, the two-scale method, and their variants such as the phase perturbation technique [D. Winebrenner & Ishimaru, Radio Sci. Vol. 20, #2, 161-170] and momentum transfer perturbation technique [E. Rodriguez, Radio Sci. in press]

Even though the above approximations and their variants show modest success with different limitations, it is important to obtain the regime of applicabilities of these approximations. In this talk, numerical comparisons of these methods will be presented for one-dimensional rough surfaces with power-law spectra. These approximate results are compared with the numerical solution obtained by method of moments.

This research was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the Office of Naval Research.

MONTE CARLO SIMULATIONS OF SCATTERING OF WAVES BY RANDOM ROUGH SURFACE PART I: FINITE ELEMENT METHOD

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Seattle, WA 98195

Recently there has been increasing interest in Monte-Carlo simulations of scattering by random rough surfaces. Numerical solutions of such large scale problems are possible with the advent of modern computers. The most common method that has been used in random rough surface scattering problems is through integral equation that is solved by the method of moments. Another technique, the extended boundary condition technique has also been used. In this paper (Part I) and the accompanying paper (Part II), we apply respectively the finite element and the finite difference methods. The attraction of these two methods is the banded nature of the result matrix equation. The results are tested against the integral equation method. The relative merits of speed and memory storage requirements for different surface heights, correlation lengths and surface lengths are compared.

To reduce the size of region of discretization in the finite element method, we have used the periodic boundary conditions. Also, the scattered fields in the homogeneous region above the maximum height of the rough surface are expanded in terms of Fourier series. The wave equation in the inhomogeneous region is solved by the finite element method.

In this paper, we consider an incident plane wave impinging upon a one-dimensional random rough surface. The surfaces are generated using Monte-Carlo surface generation routines having a Gaussian roughness spectrum with specified statistics. Numerical results are presented and are in good agreement with that of the integral equation methods for various surface heights, correlation lengths and surface lengths. For the case of small roughness, they are in good agreement with small perturbation method. The fluctuations of scattered fields will be discussed. The differences between plane wave and tapered plane wave excitations are also discussed. Numerical considerations which can improve the speed and memory storage requirements are also discussed.

THE MEAN AND VARIANCE OF DIFFUSE SCATTERED POWER AS A FUNCTION OF CLUTTER RESOLUTION CELL SIZE

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In general, the diffuse power scattered from a rough surface is calculated by making the assumption of infinite scattering cell size compared to the surface height correlation length T. For surfaces with homogeneous scattering centers, the distribution function for the scattered power tends to be Rayleigh so long as there are at least ten effective scatterers and their separation is larger than the em wavelength, λ. In this paper expressions are derived for the mean and variance of the power scattered from a one dimensionally varying rough surface for finite cell size. Results are presented showing how this affects the behavior of the scattering.

The model assumes physical optics scattering conditions so the height separation (T) is greater than λ. Thus the condition for non-Rayleigh scattering depends on the cell size and number of scatterers, The analysis considers the dependence of the mean and variance of the diffuse scattered power for a range of factors. These include cell size, rms surface height, correlation length, wavelength and bistatic scattering angles. Studying the relationship between mean and variance of scattered power allows us to assess the degree of departure of the scattered power from the Rayleigh distribution function.

NUMERICAL SIMULATION OF VERY ROUGH SURFACE SCATTERING AND COMPARISON WITH EXPERIMENT

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University of Washington
Seattle, WA 98195

Yasuo Kuga
The Radiation Laboratory
Department of Electrical Engineering and Computer Science
University of Michigan
Ann Arbor, Michigan 48109

In recent years, the existence of backscattering enchancement of light or electromagnetic waves from a rough surface has attracted considerable interest and has been studied theoretically and experimentally. Some optical experiments show that the enhancement occurs when the rms height σ is of the order of a wavelength and the rms slope is close to one. It is, however, difficult to determine the surface characteristics and statistics at optical frequencies. Satisfactory theories for very rough surfaces are not available at present. In the numerical simulation, an exact solution of the scattering problem for random surfaces with arbitrary roughness can be obtained.

In this paper we present the Monte-Carlo numerical simulation of wave scattering from one-dimensional rough surfaces and a comparison with the millimeter wave experimental results. The surface profiles are generated using the Gaussian correlation function with desired variance σ^2 and correlation length l. The incident wave is a Gaussian beam of finite width with oblique incident angle. Both TE and TM polarized incident waves are considered in this paper. The cross sections of the scattering intensities at different scattering angles are calculated for various combinations of σ and l in the neighborhood of a wavelength and for Dirichlet and Neumman surfaces. The calculations for $\sigma = l = \lambda$ are compared with the millimeter wave(75 to 100 GHz) experiment for surfaces with $\sigma = l = 3mm$ described in our previous paper (National Radio Science Meeting, Boulder, January 1990). The results show good agreement between numerical simulations and experimental data. The simulation results for a small roughness, perfectly conductive random surface are also checked with the Kirchhoff approximation and perturbation theory. Finally, we also briefly discuss the scattering of electromagnetic waves from a randomly rough dielectric surface.

A COMPOSITE MODEL FOR THE CURRENT INDUCED ON A PERFECT CONDUCTING RANDOMLY ROUGH SURFACE

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Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0111

The conventional composite surface model of scattering by randomly rough surfaces is a means for combining two asymptotic solutions in a self consistent manner. The asymptotic solutions comprise the shadowed Kirchhoff approximation and the Rice boundary perturbation result. To apply these to the actual surface, one assumes that the surface height spectrum is split into two contiguous regions. The low frequency part of the split spectrum is assumed to represent surface structure that is amenable to analysis by the Kirchhoff approximation while the boundary perturbation method is assumed to apply to the high frequency part of the surface. This composite scattering model has appeared to give a good accounting of the scattering by many natural surfaces where the basic assumptions in the model are satisfied.

Recently, there has been a great deal of interest in surfaces which do not obey the assumptions contained in the composite surface scattering model. In particular, surfaces having large slopes and curvatures have been shown to give rise to much larger scattering in the backscatter direction than would be expected based upon conventional wisdom. While numerical solutions of the one-dimensional equation for the current induced on the surface do predict a degree of enhancement, the physics of the enhancement process remain obscure.

The conventional composite surface scattering model cannot be applied to the kinds of surfaces which give rise to enhancement because the surface slopes are too large for the perturbation approximation to apply. We have recently developed a new scattering approximation which applies to surfaces which have small surface height but arbitrary slopes, curvature, etc. The purpose of this paper is to use this result to develop a new composite surface theory which may be able to explain and yield some insight into the causes of enhancement.

We start with the magnetic field integral equation for the current on the surface and show how the assumption of a product solution for the approximate current is appropriate. We then show that the large scale part of the current gives rise to long range interactions while the small scale part causes short scale effects, the scales being relative to a wavelength. The net effect of this new composite model is a result which is much more robust in its accounting for slope effects.

MONTE CARLO SIMULATIONS OF SCATTERING OF WAVES BY RANDOM ROUGH SURFACE PART II: FINITE DIFFERENCE METHOD

C. H. Chan*, L. Tsang, S. H. Lou and A. Ishimaru
University of Washington
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Scattering of waves by random rough surfaces has been studied extensively using the Rice perturbation theory and the Kirchhoff approximation. The two analytic methods are restricted in regions of validity. More recently, numerical method based on integral equation approach for the Monte Carlo simulation of rough surface scattering has been reported. In the Monte Carlo simulation, scattered field intensity is averaged over hundreds of realizations and, hence, it is important to minimize the computation time for each realization. The disadvantage of the integral equation approach is that it requires to solve a full matrix and consequently, the extensibility of the method to treat 2-dimensional random surface is limited by the available computer memory. In an accompanied paper (Part I), we report a finite element method (FEM) to the Monte Carlo simulation of rough surface scattering. In general, the number of unknowns required in this approach appears to be much more than that of the integral equation, however, the resulting sparse banded matrix significantly reduces the computer memory requirement. In this paper, we present a finite difference (FD) approach which retains the essential features of the FEM. However, the implementation of the FD approach is much easier than that of FEM which may be the key for the successful Monte Carlo simulation of 2-dimensional rough surface. Although FEM is superior to the FD in approximating the random profile and, hence, yields more accurate scattered field intensity for each realization. However, the scattering is an average quantity over hundreds of realizations and is less sensitive to the error in an individual realization. In this paper, we present an FD analysis for an one-dimensional perfect electric conducting random rough surface. Numerical results and computational time will be compared with the FEM. Numerical results for dielectric random profile will also be presented.

INTENSITY COVARIANCE AND VELOCITY PROFILE EVALUATION FOR A KOLMOGOROV SPECTRUM USING A RAMANUJAN-TYPE SERIES APPROXIMATION

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Department of Electrical Engineering, SUNY at Binghamton, Binghamton, New York 13901

ABSTRACT

The propagation of radio waves through random, turbulent media is studied commonly in terms of medium power spectral densities, structure functions, electric field correlations and intensity covariances. The problem is generally analytically intractable (and more so for higher-order moment computations), and solutions are often found either numerically or by making certain limiting approximations. A recent study (Chatterjee et al, Appl.Opt. 28, 10, 1773-1777, 1989) considered propagation in an extended stellar medium described by a Kolmogorov spectrum. Approximate analytical solutions were obtained by using a Raleigh-Ritz technique. In a study involving intensity covariance and wind velocity profile estimations, the medium power spectrum was given a form that corresponds to an intermediate range of fluctuation scale lengths (i.e. a $K^{-\alpha}$ form, where K is the wave-number, and α=11/3 is the Kolmogorov parameter). In this approach, it is shown that the slope of the two-dimensional intensity covariance function at zero time delay is directly related to a weighted integral of the wind velocity in the direction of measurement (Baram et al, Appl.Opt. 27, 2145 -2149, 1988). The novelty of this approach lies in the use of a theorem due to Ramanujan which enables evaluation of fairly complicated weighting functions in terms of series expansions.

The purpose of this paper is to apply the technique described in the work of Baram et al mentioned above to the case of a more general Kolmogorov-type spectral density (refractivity spectrum) containing a Gaussian factor in addition to the power law. In order to be able to exploit the Ramanujan theorem later, the spectrum is expanded binomially to yield two additional power terms in K (which is an extension of the $K^{-\alpha}$ form). Applying this spectrum to the expression for the slope of the covariance, after some approximations, leads to a combination of five weighting functions (W_1-W_5) which include the ones derived in the Baram et al work. By using the Ramanujan theorem to evaluate these functions, it turns out that the total weighting function may no longer be normalized uniformly in terms of the β and z/L variables introduced by Baram et al. The effects of the additional weighting functions, including the non-normalizable ones on the total weighting function and the covariance slope are explored, and compared graphically with the results for the strictly intermediate-range refractivity spectrum.

THE THIRD AND FORTH-ORDER ITERATIVE SOLUTIONS FOR THE VECTOR RADIATIVE TRANSFER EQUATION

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Recently the second-order iterative solution for the vector radiative transfer solution is obtained by applying the iterative approach to each Fourier component of the radiative transfer equation (Kuga and Ishimaru, Radio Science, 1989). Because ϕ component is expanded in Fourier series, the new second-order solution has only one integral over μ. Unlike the ordinary iterative method in which each iteration introduces double integrals over μ and ϕ, the new approach introduces only one integral over μ for each additional iteration. Hence, the new iterative method is suited for the higher order iterative solutions. We obtained the third and forth-order iterative solutions using the Fourier expansion approach. The third and forth-order solutions have double and triple integrals respectively, but with today's high speed computers we can calculate them numerically. We compared each iteration solution with the numerical solution based on the discrete ordinate method. The new iteration method is suited for large and non-absorbing particles for which the numerical solution is difficult to obtain.

Submitted to URSI Commission B

THEORETICAL STUDY OF ENHANCED BACKSCATTERING FROM RANDOM GRATINGS

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When light is reflected from some rough surfaces, the average intensity of the scattered radiation has a narrow peak in the backward direction. Under certain conditions the appearance of such a peak can be related to the excitation of surface waves. In the present work we calculate the angular distribution of light scattered from rough surfaces characterized by a locally varying surface reactance. This surface reactance is constructed as the contribution of two functions: a periodically modulated and a random one. Starting from periodically modulated surfaces we study the influence of the random roughness on the intensity and position of the peaks.

Monday PM

URSI-A Session 23

Device, Material and Medium Measurements - I

Chairs: Stuart A. Long, University of Houston; K. M. Chen, Michigan State University

Room: W-115 *Time*: 1:15-5:00

Q-MEASUREMENTS OF RESONANT CIRCUITS EXCITED BY LOSSY TRANSMISSION LINES

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Many techniques have been developed to minimize or eliminate the contributions of loss in connecting transmission lines and coupling systems when measuring the resonant characteristics of high-Q microwave and millimeter-wave resonant circuits and cavities. However, these techniques were developed for measurements made with slotted-lines and are generally difficult to implement in modern measurements using network analyzers. The Q-measurement techniques developed for network analyzer based measurements usually neglect the effects of transmission line and coupling loss, or are limited to transmission measurements where the coupling is very weak. We have extended these network analyzer techniques to account for transmission line and coupling losses, which can be used for both reflection (impedance) and transmission measurements and are not restricted to weakly coupled systems. These techniques also account for the frequency dependance of the coupling reactance, and can be readily incorporated in the measurement software or implemented in the post-processing.

Optically Controlled Dielectric Resonators on Microstrip Lines

by

Hsin-Chin Chang, Kawthar A. Zaki

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Dielectric resonators of high relative dielectric constant and temperature stability are being used extensively in applications such as filters and oscillators. One are of significant potential and practical interest is the ability to control the resonator's center frequency using optical means. Experimental investigation of the optical control of a dielectric resonator on microstrip has been investigated. The configuration is shown in Fig. 1. One end of the resonator is coated by a thin layer of a photo sensitive material (GaAs or Silicon) while the other end of the resonator rests on the dielectric substrate and couples to the microstrip line. the swept frequency $| S_{21} |$ response of the line shows an increase in the insertion loss at the resonant frequency of the dielectric resonator.

When a laser light shines on the photo conducting coating, it's conductivity changes, the boundary condition for the electric fields on the resonator's end also changes and hence the resonant frequency. Experimental measurements on a 10 GHz resonator are shown in Fig. 2. The optical control of the resonant frequency has been achieved with the light intensity. A frequency shift of approximately 20 MHz is observed.

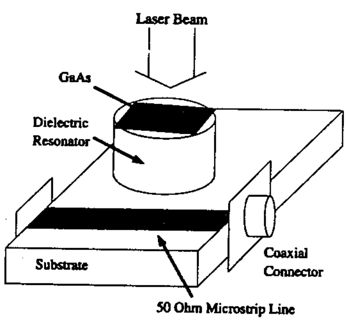

Fig.1 Configuration

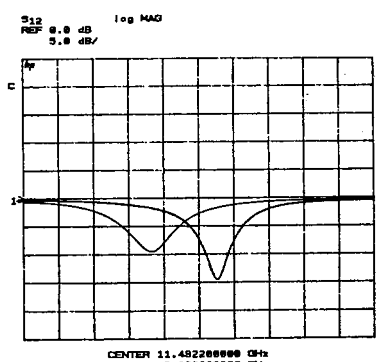

Fig.2 Experiment Result

IMPLEMENTATION OF CONFIGURABLE INTEGRATED TEST FOR MMIC PRODUCTION

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Testing and packaging may be as much as 90% of the MMIC manufacturing cost at the production stage and the cost reduction for test is essential to a successful and affordable system insertion of MMICs. A configurable integrated test (CIT) model (H. Wang et. al., 1989 IEEE GaAs IC Symposium Digest, pp. 227-230) has been developed to analyze detailed yield and cost and to predict the optimum test strategy (in terms of cost). This concept is implemented by a mathematical model which characterizes of each process/test step with test and cost parameters. This model can be used to simulate all the possible test sequences and to optimize the test strategy. The ability for quantitative prediction of all potential test strategies not only identifies the cost sensitive test step, but also provides an accurate cost estimation for MMIC chips. Implementation of test strategies developed with CIT can reduce the MMIC chip cost by 50% for some cases. The cost reduction can be higher if high efficiency and low risk test technology is implemented. This paper presents a systematic method to determine the CIT model parameters based on circuit and process parameters and realistic test options for MMIC manufacturing.

Determination of model parameters is required before using CIT to determine the optimal test strategy. We have established correlations between MMIC chip performance and device/process parameters through the circuit and process sensitivity matrices of MMIC chips. The important process, device and circuit parameters that affect the MMIC's RF performance and yield have been identified. Consequently, we developed a technique to calculate CIT model parameters corresponding to the critical process/test steps. For example, DC functional test is found to be unnecessary for some MESFET amplifier MMIC chip production via estimated model parameters.

Wafer and DC/RF circuit screening for GaAs MMIC manufacturing has been extensively investigated. A test element group (TEG) has been designed for in-process control monitoring and post-process wafer qualification. Good correlation between TEG and MMIC chip performance was observed. Based on this information CIT model parameters were determined and CIT was used to delineate whether limited or extensive testing (DC and/or RF) should be performed.

The CIT model with the aforementioned features can be used to predict accurate chip yield and cost and determine the optimal test strategy. Several application examples of this model for both monolithic HBT microwave IC and 0.25 μm MESFET millimeter wave IC will be presented to demonstrate its importance in reducing MMIC chip cost.

MODEL MEASUREMENTS FOR DESIGNING A PLANAR DIODE, SUBMILLIMETER-WAVE MIXER

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Planar Schottky diodes have recently been fabricated at the University of Virginia with parasitic element values comparable to those of the traditional whisker-contacted ones. Designing a submillimeter-wave mixer using these planar diodes requires scale model measurements of the diode parasitic elements as well as measurements of the mixer block, which in our case includes a probe to couple energy from a circular waveguide to a shielded microstrip, a non-contacting adjustable short to tune the probe, a quarter-wavelength DC return bondwire, and an RF choke to prevent coupling of RF power into the IF/DC circuit.

The composite microstrip line, DC return, probe transition, and non-contacting short should couple power efficiently over the circular waveguide single-mode bandwidth. Probe measurements using a contacting tuning short suggest that a particular probe printed on a quartz substrate which extends completely across the circular waveguide has a multi-mode insertion loss of -20 dB over a bandwidth of 22%. This bandwidth reduces to 10% when single mode propagation is required in the circular waveguide, as is desirable for mixer operation. Measurements on the adjustable non-contacting short indicate that four quarter-wavelength sections of alternately low and high impedance coaxial line form a short with excellent phase and magnitude response over the single-mode bandwidth for a circular waveguide. The quarter-wave DC return bondwire has little effect on the mount impedance, especially when the DC return line is located at a half-wavelength away from the waveguide opening of the shielded microstrip. With the scale models constructed in a modular fashion, the various parts can be connected to measure the interaction between them. In addition, impedance can be measured from the terminals of the diode by connecting a micro-miniature coaxial cable to these terminals and using this cable as the DC return line. The embedding impedance of the mount can then be measured at several harmonics of the fundamental LO frequency and an accurate characterization of mixer performance can be obtained.

Non-Specular Scattering from Roughened Aluminum Surfaces

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Measurements of radiation scattered from roughened aluminum surfaces were performed at 10.6 microns. The incident radiation was linearly polarized parallel to the scattering surface and the scattered radiation was measured in two polarization states; parallel, σ_0 (HH), and perpendicular, σ_0(HV), to the scattering plane. In the laboratory set-up, the propagation vector of the incident radiation and the detector arm are constrained in a horizontal plane. The propagation direction is fixed and the detector arm is movable. The simulation of conventional scattering angles θ_i, θ_s, ϕ_s, require that the scattering surface be rotated around two directions. The data were compared to the predictions of Papa, Lennon, and Taylor (IEEE Transactions on Antennas and Propagation, Vol. AP-34, No. 10, October, 1986). Excellent agreement was obtained when the ratio of σ_0 (HH) / σ_0 (HV) was compared to theory for scattering angles within 20 degrees of the specular direction. For larger angles we observed the onset of depolarization. Measurements were also done on the same roughened aluminum surface with 633 nm radiation. The details of the laboratory set-up, transformation of conventional to laboratory angles, and data will be presented and discussed.

A BISTATIC LIDAR SCATTERING MEASUREMENT SYSTEM: DESIGN, FABRICATION, AND EXPERIMENTAL RESULTS

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Electromagnetic wave interaction with random media is a process which needs improved theoretical representations. Existing assumptions and approximations sometimes remain unjustified since this scattering phenomena is not fully understood. Experimental techniques need improvement and advancement in order to contribute to the research of a mathematical model that predicts the scattering process more completely. A bistatic lidar scattering measurement system has been constructed to satisfy this need and to serve as a tool used to better describe wave interaction with random media.

The transmitter for the active system is a linearly polarized, 5 mW helium-neon laser which operates in the red ($\lambda = .633\ \mu m$). The laser beam is amplitude modulated in the form of a pulse train which is synchronously detected by the receiver. The receiving optics consists of a collecting lens, spatial filter, collimating lens, beam splitting polarizing cube, and two photodetectors for measurement of both polarized and cross-polarized returns, which helps assess the surface and subsurface contributions to the scattered radiation pattern. The receiver also has electronic amplifiers and filters to condition and average the received pulses. The system is automated and consists of a spherical frame over which the transmitter and receiver travel. The transmitter and receiver design, system automation, and system architecture are discussed in this work.

Bistatic and monostatic measurements are reported as evidence of the accuracy, repeatability, and utility of the system.

RADAR TARGET DISCRIMINATION OF NEARLY IDENTICAL TARGETS USING FREE-FIELD MEASUREMENTS

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Recent work has demonstrated the feasibility of discriminating several different aircraft targets using measured time-domain data. In that work, the scattered field response of a target measured inside an anchoic chamber is convolved with an E-pulse waveform to produce a signature based on the target natural resonances. By use of this unique signature, the target can be discriminated from others. In general, nearly identical targets are very difficult to discriminate since their natural resonances are close to each other.

This paper will investigate discrimination of nearly identical airplane models. The targets consist of a 1" diameter 12" long cylinder as a fuselage and 0.25" diameter, 4" to 8" long cylinders as wings. The wings are attached at three different angles, 90, 45, and 30 degrees to the axis of the fuselage.

Measurements are made using the MSU free-field transient range, which consists of a 12'x12'x24' anechoic chamber, with wideband horn antennas used both for transmitting and receiving. The horn antennas have been loaded with a distributed resistance to eliminate the strong resonances which often occur near the target natural resonances. Excitation is provided using a 0.5 ns pulse of amplitude 40V, and the received waveform is digitized by a waveform processing oscillscope.

Initial results appear quite encouraging. Aircraft having only slightly differing wingspans were discriminated.

UNIQUE AND SIMULTANEOUS DETERMINATION OF THE COMPLEX ε AND μ OF COMPOSITE MATERIALS USING BISTATIC, FREE SPACE MEASUREMENTS ON PLANAR SAMPLES

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A free space method for simultaneous measurement of the complex permittivity ε and complex magnetic permeability μ of composite materials at microwave frequencies has been implemented and tested successfully. The method used the complex Fresnel reflection coefficients of the sample for both parallel and perpendicular polarization, which were measured using a free space bistatic setup. The setup used consisted of two spot-focused horn lens antennas connected to a vector network analyzer which enabled us make complex reflection measurements. The main beam of the antenna illuminated a circular area 1" in diameter at a distance of 12" and the resultant wave was a plane wave. A new one port, bistatic free space calibration method has been implemented and used successfully to eliminate magnitude and phase measurement errors in the set-up. Details of the calibration procedure and a discussion of the experimental results are presented. The accuracy of this method relative to other methods are compared.

THE EFFECTIVENESS OF A C-BAND ATTENUATION CORRECTION PROCEDURE TESTED ON SIMULATED WEATHER RADAR MEASUREMENTS

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The advantages offered by the use of C-band weather radars are well known, consisting in a lower cost and smaller dimensions in comparison with conventional S-band radars. The much greater propagation attenuation effect due to rain that they experience is the penalty that C-band radars nndergo. In particular, dual polarization radars rainfall rate estimates can be so strongly corrnpted by differential attenuation effects, that it would be absolutely meaningless to rely on absolute and differential reflectivity data provided by such radars in order to analyze rainfall parameters. Nevertheless, since efficient attenuation correction algorithms have been developed, the attenuation effects on the rainfall rate estimate can be minimized to such an extent that the use of C-band radars has been suggested as a standard for the Enropean meteorological network.

The purpose of this work was to evidence the reliability of attenuation corrected data, making use of a more general model which allows to generate time sequences of radar absolute and differential reflectivity fields related to a given rainfall event evolving in space and time. It was first simulated the effect that attenuation has on both horizontal and vertical polarization channels, resorting to empirical relationships obtained by means of disdrometer measurements and based on the high degree of correlation existing between specific attenuation and reflectivities. Calibration errors of the radar were also taken into account before applying the attenuation correction procedure, which is essentially an extension of a single polarization algorithm to the dual polarization case. It consists in a iterative process that is carried on at each range gate, starting from the nearest to the radar, and allows for already corrected values in the previous gates.

The results arising from the comparison between the 'true', attenuation corrupted and corrected reflectivity values evidenced a highly satisfying behaviour of the correction procedure, even in presence of a remarkable bias of the calibration error. Furthermore, since the employed simulation model is closer to the real radar acquisition process, the results show that the performance of the procedure could be even better than foreseen when it was first introduced.

Millimeter Wave Attenuation Through Moving Rectangular Spot Illuminated Semiconductor Panel

M. H. RAHNAVARD and A. Bakhtazad

EE Dept., School of Engg., Shiraz University, Shiraz, Iran

One of the needs in air traffic is to know the environmental situation under any weather conditions. Visible and i.e. radar will fail in adverse weather because of high at attenuation, but there are several windows in the millimeter-wave region with low attenuation in bad weather conditions. One of the ways of converting millimeter-wave to visible light is to use an illuminated semiconductor panel. Semiconductor panels are used as image convertors in both transmission and reflection modes of operation. In both cases, the response of an illuminated panel is important. Excess carrier density in moving-spot illuminated semiconductor panel is studied, and profiles of the excess carrier density for a moving-strip-illuminated semiconductor panel as a function of different parameters is obtained (M. H. Rahnavard et. al., Moving spot illumination of semiconductor panels, J. Appl. Phys., 46(1975) 1229-1234). Attenuation through moving-strip illuminated semiconductor panels as a function of scanning velocity, width of the strip, time, etc. are also studied (Rahnavard, et. al., millimeter wave attenuation through and reflection coefficient from moving strip illuminated semiconductor panel, Sensors & Actuator, 12 (1987), pp. 367-374).

In practice, the response of a semiconductor panel to moving spot illumination is required. In this paper attenuation through moving rectangular spot illuminated semiconductor panel as a function of position, velocity, time, spot size are studied.

Monday PM

Joint AP-S, URSI-B Special Session 25

Polarization Radar Theory

Chairs: Wolfgang-M Boerner, The University of Illinois at Chicago; A. I. Kozlov, Moscow Civil Aviation Engineering Inst.

Room: W-110 *Time*: 1:15-5:00

1:20	**Basic Equations of Radar Polarimetry and its Solutions: the Characteristic Polarization States for the Coherent Case** Wolfgang-M Boerner*, An-Qing Xi, The University of Illinois at Chicago; Yoshio Yamaguchi, Niigata Unviersity	118
1:40	**Basic Equations of Radar Polarimetry and its Solutions: the Characteristic Mean Polarization States and its Spread for the Partially Polarized Case** Wolfgang-M Boerner, Wei-Lin Yan, The University of Illinois at Chicago; Amit P. Agrawal*, Northern Illinois University; Mitsuro Tanaka, Oita University	119
2:00	**On the Problem of the Polarimetric Contrast Optimization** Shi-Ming Lin*, Jian Yang, Northwestern Polytechnical University	AP-S
2:20	**Eigenvalue Problem and Kennaugh's Optimal Polarization for the Asymmetric Scattering Matrix Case** Shi-Ming Lin*, Northwestern Polytechnical University	AP-S
2:40	**On the Huynen's Target Characteristic Parameters** Shi-Ming Lin*, Northwestern Polytechnical University	AP-S
3:00	**Coffee Break**	
3:20	**Properties of Scattering Matrix Determination** A. I. Kozlov*, A. I. Logvin, Moscow Civil Aviation Engineering Inst.	AP-S
3:40	**Scattering Matrix for Non-Linear Transformation Electromagnetic Waves** A. I. Logvin*, A. I. Kozlov, Moscow Civil Aviation Engineering Inst.	AP-S
4:00	**From Coherence Matrix to Antenna Space** L. A. Zhivotovsky*, V. I. Ul'ynov, LETI	AP-S
4:20	**Improved Polarization Detect and Discriminate in Radars** A. I. Kozlov*, A. I. Logvin, Moscow Civil Aviation Engineering Inst.	AP-S
4:40	**Basic Theory of Passive Microwave Radiation Polarization Losses Matrix and Imaging** A. I. Kozlov*, A. I. Logvin, Moscow Civil Aviation Engineering Inst.	120

BASIC EQUATIONS OF RADAR POLARIMETRY AND ITS SOLUTIONS: THE CHARACTERISTIC POLARIZATION STATES FOR THE COHERENT CASE

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and

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Radar polarimetry has become an indispensible tool in modern electromagnetic sensor technology. A comprehensive overview of the basic principles is presented together with the field operations for both the coherent and the partially coherent cases. In a next step the Jones vector and scattering matrix [S] are introduced together with the change of polarization transformations, whereupon the concept of the characteristic polarization states is developed. Various methods and mathematical formulation for the solution are compared and interpreted and it is shown that the polarization transformation (ρ) representation is valid and the most straightforward method of determining the four pairs of characteristic polarization states: the pair of orthogonal co-polarization maximum states which for the monostatic reciprocal case is identical to the pair of cross polarization minimum states; the pair of co-polarization null states; and the pair of cross polarization maximum states which all lie on one main circle, the target characteristic polarization state locus. Examples for simple targets are presented.

BASIC EQUATIONS OF RADAR POLARIMETRY AND ITS SOLUTIONS: THE CHARACTERISTIC MEAN POLARIZATION STATES AND ITS SPREAD FOR THE PARTIALLY POLARIZED CASE

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The optimal reception of polarized radar waves for the monostatic (backscatter) case for both the completely polarized and the partially polarized cases are analyzed and compared. It is shown that there exist four distinct optimization problems for the partially polarized case for which the specific solutions are given and interpreted in comparison to previous analyses in the literature. Specifically it is shown that optimal reception of the purely polarized wave component reduces to Kennaugh's characteristic polarization state concept for the coherent case. It is also shown that for the general partially polarized case there exist four pairs of characteristic polarization states, of which the two orthogonal maximum co-polarization (identical to pair of cross-polarization null) states are equivalent for the coherent and partially polarized cases. For a general target case the mean states and their variances (cluster-radii) are determined and the applicability of this useful concept is demonstrated.

BASIC THEORY OF PASSIVE MICROWAVE RADIATION POLARIZATION. LOSSES MATRIX AND IMAGING

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Moscow Civil Aviation Institute

The article shows that the polarization condition of electromagnetic waves emitted can be described through 3x3 matrix, the elements of which are determined by both anisotropic properties of the object emitting and polarization and electric losses of some special wave. It is shown that at long distances the losses matrix (LM) coinsides with the coherent matrix of a wave emitted. The dependence of the LM on the polarization basis is found, special bases concept is introduced, this matrix invariants are determined and their phisical essence is given. The possibility of presenting the LM through brightness temperature taken on four polarization types is shown, which makes it possible to show the ways of its experimental determination. The analysis of the LM makes it possible to express it directly through the characteristics of the emitting object (invariant to the replacement of polarization basis-object total radiation capability and the extent of its anisotropy and noninvariant ones-apparent extent of anisotropy and some angle on Poincare's sphere). Such presenting makes it possible to speak of the time-varying four-dimention image of an object and its projecting to a less dimention space. Moreover, such a presentation opens a way to directly measuring the characteristics of the object but not the wave emitted. It is based on the brightness temperatures formulas transformation. The LM presentation mentioned above makes it possible to give a total classification of objects among which two limited-objects can be signed oot (isotropic-polarization and defective ones). The ways of solving inverse problems connected with determination of complex dielectric permitivity and thermodynamic temperature are shown. It is also shown that despite the incorrectness of such problems rather trues values of the parameters can be obtained. It is based on the redunded information which can be obtained by measuring at different angles and polarization.

REFERENCES

Богородский В.В., Козлов А.И., Логвин А.И. Микроволновая радиометрия земных покровов. Л. Гидрометеоиздат, 1985.

Tuesday AM
URSI-B Session 26
Numerical Methods - Antennas and Scattering

Chairs: A. C. Cangellaris, The University of Arizona; D. R. Wilton, University of Houston
Room: W-107 *Time*: 8:15-12:00

ELECTROMAGNETIC SCATTERING FROM 3D DIELECTRIC BODIES USING THE MAGNETIC FIELD INTEGRAL EQUATION FORMULATION

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Numerous applications require accurate models for predicting the scattering from finite, inhomogeneous 3D dielectric bodies. Existing formulations often employ the electric-field integral equation. This paper will describe a new formulation based on a volume discretization of the magnetic field integral equation (MFIE). The approach is an extension of a 2D formulation developed by Peterson and Klock ("An improved MFIE formulation for TE-wave scattering from lossy, inhomogeneous dielectric cylinders," *IEEE Trans. Antennas Propagat.*, vol. AP-36, pp. 45-49, Jan. 1988).

The MFIE is discretized over tetrahedral cells using a piecewise-linear representation for the total magnetic field and point matching at the cell vertices. The piecewise-linear representation can be obtained using either node-based or edge-based functions, and both are currently under consideration. Node-based expansion functions enforce the continuity of all three components of the vector field, while edge-based functions only explicitly enforce continuity of tangential components at cell interfaces (further generalizations to include magnetic material require a discontinuity in the normal component of the magnetic field.) Although numerical solutions obtained using the node-based functions exhibit very small divergence within homogeneous cells, the edge-based expansion functions satisfy the desired zero divergence property exactly (Tanner and Peterson, "Vector expansion functions for the numerical solution of Maxwell's equations," *Microwave and Optical Technology Letters*, pp. 331-334, Sep. 1989).

Despite the volume discretization, the matrix "fill" associated with the MFIE formulation for a 3D dielectric scatterer involves only two-dimensional numerical integration over the faces of the tetrahedral cells. Numerical results will be presented and compared with exact solutions for homogeneous spherical scatterers. Some practical difficulties associated with the use of tetrahedral models will be discussed.

SCATTERING FROM AN ARBITRARY CYLINDER IN THE PRESENCE OF A PLANAR MEDIA INTERFACE USING THE BYMOMENT METHOD: PART ONE, THEORY

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Because of the versatility of the finite-element method (FEM) in handling geometries of arbitrary cross-section and material properties, its use in solving electromagnetic scattering problems has increased in recent years. A major difficulty in applying FEM to unbounded regions is developing a technique to properly truncate the FEM mesh. Although several methods are presented in the literature to handle the truncation in free space, there is very little available for problems involving media interfaces. In this paper, we apply the bymoment method to this problem. Both the TM and TE polarizations are considered

The finite-element method is used to generate the a set of linearly independent solutions over the region occupied by the cylinder, using a grid which is truncated at a small distance from the scatterer by a surface which conforms to the cross-section of the cylinder. We then couple the properties of the region exterior to the FEM mesh to the interior solution using Green's theorem in conjunction with a set of linearly independent functions which satisfy the boundary conditions along the interface and at infinity. One such function is the Green's function which accounts for the media interface. By choosing different N locations for the line source of the Green's function, we obtain a set of N linearly independent functions.

SCATTERING FROM AN ARBITRARY CYLINDER IN THE PRESENCE OF A PLANAR MEDIA INTERFACE USING THE BYMOMENT METHOD: PART TWO, NUMERICAL RESULTS

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In the previous paper, we developed the theory for solving the problem of scattering from a cylinder near a media interface using the bymoment method to truncate the finite-element mesh around the cylinder. In this paper, we present the numerical results for various cases. The incident field in all cases is assumed to be a plane wave. Entire domain sinusoidal basis functions are used to expand the solution on the boundary of the mesh. The Green's function for the media interface problem is used to generate a set of linearly independent testing functions.

In order to validate this theory, our results are compared to method of moment results for the case of scattering from perfectly conducting circular cylinders. The numerical results are presented in terms of the surface current on the cylinders. Results are also shown for dielectric cylinders both above and below the interface. For these cases, the far-field results are given. To demonstrate the versatility of this method in handling inhomogenous and arbitrarily shaped cylinders, we consider the case of two circular dielectric cylinders either above or below the interface where the mesh encompasses both cylinders. In order to show its ability to handle fairly large cylinder, we will present the results for a circular dielectric cylinder of radius $1.7\lambda_d$ where λ_d is the wavelength in the dielectric cylinder.

TE PLANE WAVE SCATTERING BY A DIELECTRIC CYLINDER LOADED WITH PERFECTLY CONDUCTING STRIPS.

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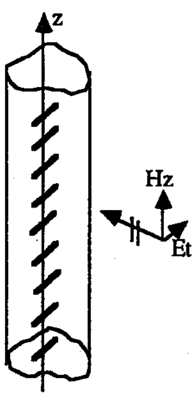
The scattering by a dielectric cylinder can be reduced significantly by loading the cylinder with perfect electrically conducting (pec) strips parallel to the incident electric field. This paper presents a method for analyzing the TE plane wave scattering from a dielectric cylinder loaded with pec strips of finite length that are oriented perpendicular to the cylinder axis. In addition to the strips being narrow, the strip configuration is assumed to be periodic along the cylindrical axis.



The problem is formulated in terms of the currents on the strips and these currents are expanded in terms of pulse basis functions. An Electric Field Integral Equation (EFIE) for the unknown currents is formulated by forcing the tangential component of the electric field along the strips to vanish. As a preamble to solving the EFIE, a numerical Green's function is constructed to describe the the fields produced by a periodic array of current elements residing on the strips and radiating in the presence of the dielectric cylinder. This (matrix) Green's function is obtained by taking the periodicity of the structure into account as follows. The fields associated with each of the basis functions are expressed as a superposition of a discrete set of fields, each characterized by a fixed value of the propagation constant k_z along the cylinder axis. The fields for a specific k_z are solved for by formulating a surface integral equation for the dielectric cylinder and matching the fields in free space with the fields in the dielectric cylinder caused by a strip current. The total field due to a pulse basis function is calculated by summing up the contribution of the fields associated with individual k_z components.

The Induced Field Ratio (IFR) concept provides us with an elegant way to quantize the forward plane wave scattering from cylindrical structures. However, since the structure under investigation is not truly two-dimensional, the validity of standard IFR formulas may be questioned. It will be shown that the IFR theory can still be utilized to describe the scattering from a dielectric cylinder periodically loaded with pec strips perpendicular to the cylinder axis. It is also shown that the asymptotic formulas derived in connection with the IFR to predict this ratio from a horn measurement generally remain valid.

Numerical results that exhibit the effect of the presence of the pec strips on the scattered fields of a dielectric cylinder and its IFR will be provided in the paper.

SURFACE INTEGRAL EQUATION FORMULATIONS FOR IMPEDANCE SCATTERERS IN THE PRESENCE OF PURE DIELECTRICS*

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To date the problem of scattering from pure (perfectly) dielectric materials in the presence of imperfectly conducting bodies, when the dielectric surface can not be treated using the Impedance Boundary Conditions (IBC), has received little attention. However, the problem of perfectly or imperfectly conducting bodies coated with a dielectric layer can be solved using the IBC. The problem of scattering from perfectly conducting and dielectric bodies and their combinations has been the focus of attention of many investigators. It is more useful to develop a general formulation of the combination of surface impedance and dielectric objects.

The IBC approach relates the tangential components of the electric fields to those of the magnetic fields via an impedance factor which is a function of the surface materials. For closed bodies, it has been previously shown that the IBC is a valid approximation to the exact solution whenever (a) the refractive index is large compared with unity, (b) the total radii of curvature are much greater than the penetration depth (skin depth), (c) the body is much thicker than the penetration depth, and (d) the spatial variation of the index of refraction is slow in comparison to the local wavelength. Consequently, the impedance boundary condition concept has been utilized to solve many electromagnetic problems. The existence of a pure dielectric material with an imperfectly conducting one, on the other hand, requires consideration of the exact boundary conditions on the dielectric surfaces (continuation of the tangential components of the electric and magnetic fields on the dielectric surfaces). Such penetrable surfaces can not therefore be treated using the impedance boundary condition. Accordingly, in this case, a different approach, in which some kind of mixed boundary conditions has to be taken. In this paper, different formulations are developed. The method of moment is then used to reduce the integral equations into a matrix equation for axisymmetric objects. The bistatic and monostatic radar cross-sections are calculated for different geometries of coated and partial coated impedance surfaces.

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*This work was supported by the National Science Foundation under Grant No. ECS-8906807.

EFFECT OF APPROXIMATIONS IN THE FORMULATION OF THE MIXED-POTENTIAL INTEGRAL EQUATION

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The mixed-potential integral equation which explicitly incorporates both the vector and scalar potentials is widely used for the numerical solution of electromagnetic radiation and scattering problems. The well-known MININEC wire code and the triangular patch code for arbitrary surfaces are based on the mixed-potential integral equation formulation. Various approximations are commonly made in the formulation of the equations to reduce the complexity or the number of numerical integrations required in the evaluation of the potentials and the integrals resulting from the moment method testing procedure. In the MININEC code, for example, pulse basis sets are used to represent both the current and the charge. This approach may be viewed as an approximation to the use of a triangle basis set for the current which, when differentiated, yields the same pulse basis set for the charge. Another commonly made approximation is the evaluation of the testing integral for the vector potential term contribution to a matrix element via a one-point rectangular rule integration.

Results of recent work using the mixed-potential integral equation suggest that such approximations may have a detrimental effect on the convergence rate of the solution for larger structures, even though the number of unknowns per wavelength used in the numerical model remains constant. In this paper the effect of some of these approximations in the mixed-potential integral equation formulation is further investigated. The problems of electromagnetic scattering by a flat two-dimensional infinite strip and a circular cylinder illuminated by a plane wave with electric field oriented transverse to the body axis are employed as test cases for evaluating the effect of the approximations in the formulation.

FINITE GROUND PLANE EFFECTS ON LINEAR ARRAYS

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Previous investigations on linear phased arrays have mainly dealt with arrays located in free space or on an infinite conducting or penetrable planar interface. The effects of ground plane curvature and finiteness were not explicitly considered because these lead to analytically intractable problems. In this presentation, a general integral equation based formulation is developed for general linear arrays, having periodically located elements along an axis. The elements may be arbitrarily configured and are represented by thin wire segments. The array is embedded in a finite ground plane of arbitrary profile transverse to the array dimensions. A computationally efficient Floquet-Galerkin method is described to solve the resulting integral equations. Comparisons are made with published results for monopole and dipole arrays on infinite ground planes. The effect of ground plane curvature and finiteness will be explored parametrically. Optimized beam shaping along and transverse to the array axis achieved with various ground plane terminations and radiating elements will be presented.

NUMERICAL MODELING OF MULTI-ARM SPIRAL ANTENNAS

Nathan J. Champagne, Shian-Uei Hwu, Robert M. Sharpe,
Jeffery T. Williams*, and Donald R. Wilton
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To aid in the identification of some of the problems associated with the feeding and resistive loading of spiral antennas we have developed a numerical algorithm, using a mixed potential/method of moments formulation, for the analysis of multi-arm spiral antennas in free space. In general, the antenna is treated as a combination of wires and thin metal conductors, which will be modeled using linear wire segments and triangular patches, respectively. This algorithm takes advantage of the discrete rotational symmetry of the general spiral antenna by treating it as a discrete body of revolution (DBOR). This solution technique significantly reduces the large computational storage requirements and solution times associated with modeling electrically large spiral antennas. The analysis accounts for multiple, arbitrarily located excitations and is capable of determining far field patterns and impedance characteristics. Transmission line feed structures and resistive loading of the antenna arms are also incorporated and results will be shown which demonstrate how these features affect the radiation and impedance properties of the spiral antenna.

ANALYSIS OF AN INFINITE PERIODIC ARRAY OF ARBITRARILY BENT THIN WIRE RADIATORS WITH MULTIPLE DIELECTRIC LAYERS

Surendra Singh* and Hassan M. Mannaa
Department of Electrical Engineering
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Tulsa, Oklahoma 74104

A computationally efficient algorithm for determining the radiation characteristics of an infinite periodic array of arbitrarily bent thin wire radiators with multiple dielectric layers is presented. Each radiator may comprise several wire segments to form junctions. The array lattice may be rectangular or triangular. Analysis is first presented for determining the radiation characteristics of an infinite periodic array of arbitrarily bent thin wire radiators in free space and over a ground plane. The analysis is then extended to treat an array covered with multiple dielectric layers. A numerical procedure using an integral equation approach is outlined and solved by the method of moments. The procedure involves a mixed potential integral equation which significantly simplifies computer code development.

The periodic Green's function, which is represented by a doubly infinite series, converges slowly especially when both the source and observation points are in the same plane. Two techniques for enhancing the convergence of the periodic Green's function series are employed in the code. This is expected to be necessary in order to sufficiently reduce the computation time required to solve a given problem so that the resulting code could be used for design purposes. Numerical results include active impedance as a function of scan angle for both E-plane and H-plane scans. Also, the effect of using acceleration techniques is shown by providing time estimates with and without acceleration of Green's function series.

Radiation Pattern and Input Impedance of Dipole-fed Horn Antennas

G.V. Eleftheriadis, P.B. Katehi, W. Y. Ali-Ahmad and G. M. Rebeiz *

NASA / Center for Space Terahertz Technology
Electrical Engineering and Computer Science Department
The University of Michigan
Ann Arbor, MI 48109-2122

Abstract: The radiation characteristics of a single rectangular horn fed a strip-dipole are rigorously analyzed. The dipole-fed horn is a novel millimeter-wave antenna used for focal-plane imaging arrays and phased arrays. In this configuration, a strip dipole is suspended in an etched pyramidal cavity, and the fabrication process is entirely monolithic. The horn is approximated by a structure of multiple rectangular waveguide sections one of which contains the excitation. The fields in each section are given by a linear combination of waveguide modes and the fields in air are given by a continuous plane-wave spectrum. To evaluate the input impedance, the electric current density on the surface of the strip-dipole is computed by solving Pocklington's integral equation using the method of moments. Upon determining the current density on the dipole, the fields at the horn aperture are calculated by matching the boundary conditions at each of the waveguide discontinuities, and at the aperture of the horn. The far-field pattern is found from the Fourier transform of the electric field on the aperture of the horn. The theoretical impedance calculations will be compared with 1-2GHz scale-model measurements, and the pattern calculations with a 94GHz monolithic horn antenna.

Tuesday AM
URSI-B Session 30
Chiral Media

Chairs: Dwight L. Jaggard, The University of Pennsylvania; Ismo V. Lindell, Helsinki University of Technology

Room: W-109 *Time*: 8:15-12:00

CHIROLENS AS A BIFOCAL LENS

Nader Engheta*
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University of Pennsylvania
Philadelphia, PA 19104

and

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The Institute of Optics
University of Rochester
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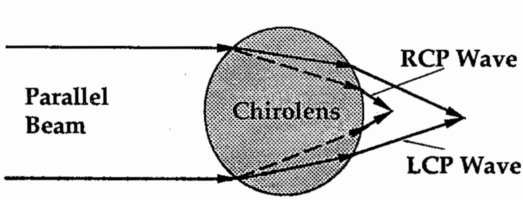
It is known that an isotropic chiral or optically active material can be characterized by the set of constitutive relation $\mathbf{D} = \varepsilon\mathbf{E} + i\xi_c\mathbf{B}$ and $\mathbf{H} = (1/\mu)\,\mathbf{B} + i\xi_c\mathbf{E}$ where the additional chirality admittance parameter ξ_c is introduced to account for the new characteristics resulting from the medium's handed constituents. Furthermore, it has been shown that electromagnetic wave propagation in such isotropic media displays two unequal characteristic wave numbers for right- and left-circularly polarized (RCP and LCP) eigenmodes. Since a variety of new optical, millimeter wave, and microwave devices may be devised by employing a chiral medium instead of an ordinary dielectric, chiral materials and *electromagnetic chirality* which represents the role of chirality or handedness in electromagnetics, have been extensively investigated in recent years.

Recently we have introduced the idea of a spherical *chirolens*: a homogeneous lens made from isotropic chiral materials (N. Engheta & M. W. Kowarz, *J. Appl. Phys.*, Vol. 67, No. 2, 1990). In this talk, the properties of electromagnetic wave propagation through the spherical chirolens are analyzed and presented using a rigorous electromagnetic approach based on dyadic Green's functions. We demonstrate that homogeneous spherical chirolenses possess two distinct focal points for two eigenmodes as shown in the Figure below. The relative locations of the two focal points are given as a function of chirality parameter ξ_c. It is also shown that under some conditions, such lenses can focus one of the modes while defocusing the other. Potential applications of chirolenses to couplers for waveguides, polarization filters and new antennas for remote sensing are also addressed.



MODAL THEORY FOR A CHIRAL - DIELECTRIC CABLE

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Propagation in a circular metallic waveguide filled with chiral material has been examined recently (C. Eftimiu and L.W. Pearson, Radio Science, 24, 351-359, May-June 1989). In the present work, the analysis is extended to a cable whose core is constituted of chiral material. If r is the radial distance from the symmetry axis of the cable, the region $o \leq r \leq a$ is a cylindrical core of chiral material; the region $a \leq r \leq b$ is filled with a homogeneous isotropic material characterized by scalar permittivity and permeability constants, and $r = b$ is a perfectly conducting wall.

The dispersion relation for the above structure is analyzed, and the modes which can exist in the structure are examined. Dispersion curves and plots of field lines for several modes are exhibited. A physical interpretation of the results obtained is provided, and possible advantages of using chiral media are discussed.

CHIRAL MICROSTRUCTURES: THEIR FREQUENCY RESPONSE

Nader Engheta and Dwight L. Jaggard
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Owing to the handed nature of their constituents, isotropic chiral or optically active materials exhibit handedness properties when electromagnetic waves interact with them. These media are described by the constitutive relations $\mathbf{D} = \varepsilon\mathbf{E} + i\xi_c\mathbf{B}$ and $\mathbf{H} = (1/\mu)\,\mathbf{B} + i\xi_c\mathbf{E}$ where the chirality admittance ξ_c is a measure of the material handedness. The characteristic plane waves propagating in a homogeneous isotropic chiral medium are right- and left-circularly polarized (RCP & LCP) waves, possessing differing propagation wave numbers.

One of the important and challenging problems in the area of electromagnetic wave propagation and radiation in chiral media is the dependence of material parameters, i.e., ε, μ, and ξ_c, on frequency of the interacting wave. In this talk, using appropriate models and a physically motivated approach, we analytically study the frequency response of chiral materials examining the interaction of electromagnetic waves with its constituent chiral microstructures. In the low frequency approximation, we have studied and already reported in the literature the scattering properties of a single-turn metallic helix when it is illuminated by a monochromatic plane wave in terms of its physical dimensions. In the present investigation, we extend the frequency regime and present the frequency response of the single-turn helix over a broadband regime. The bulk or macroscopic properties of chiral materials are then obtained from an appropriate summation of the response of the microstructures. A straightforward algorithm to describe electromagnetic wave interaction with isotropic chiral materials as a function of frequency has been found. The results of this investigation will allow one to study the transient response of chiral composites. This has applications to problems of chiral composites in a pulsed radar environment.

CHIROSHIELD†: THE CHIRAL SALISBURY SHIELD

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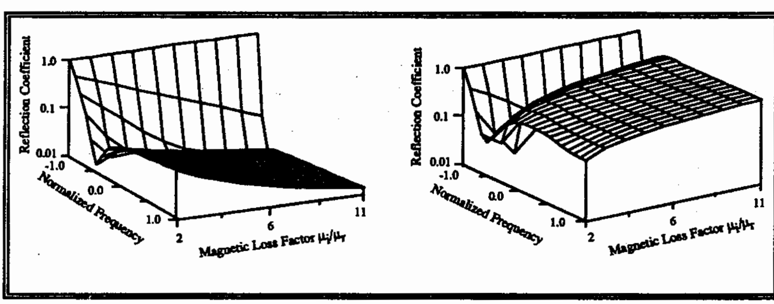
University of Pennsylvania
Philadelphia, PA 19104

Simple plane wave propagation in chiral media is characterized by a pair of eigenmodes, their corresponding wavenumbers $k_{\pm} = \pm\, \omega\mu\xi_c + \sqrt{k^2 + (\omega\mu\xi_c)^2}$ and chiral impedance $\eta_c \equiv \eta/\sqrt{1 + \eta^2 \xi_c^2}$ with η and ξ_c being the background impendance and chirality admittance, respectively.

Our interest here is to investigate the interaction of electromagnetic waves with chiral layered structures with a view to modifying the reflection coefficient of planar structures. For structures of other shape, similar techniques can be used to modify radar cross section. The principles invoked are those used in the development of *chirosorb* [D. L. Jaggard & N. Engheta, *Electronics Lett.* 25, 173-174, 1989]. The starting point for this work is the development of a *chiral Riccati equation* which relates the reflection coefficient to the (sometimes complex) material parameters, ε, μ and ξ_c.

Since chirality offers additional degrees of freedom for the synthesis of layered structures, one can fabricate a Salisbury shield alternative which we denote chiroshield. Below is shown one example in which the reflection coefficient for a covered metallic surface is displayed. On the left is the chiral case and on the right its achiral (nonchiral) counterpart for a lossy magnetic layer.



Reflection from Chiral Shield **Reflection from Achiral Shield**

† Patent pending

Comparison of Models for Chiral Media

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RADC/EECT
Target Characterization Branch
Applied Electromagnetics Division
Hanscom AFB, MA 01731

The consitutive relations which describe a chiral (optically active) medium are necessarily empirical, and different authors have employed subtly different forms depending on personal judgement and intended applications. The three most commonly used forms are

$$\mathbf{D} = \epsilon\mathbf{E} + \alpha\dot{\mathbf{H}} \qquad \mathbf{B} = \mu\mathbf{H} + \alpha\dot{\mathbf{E}} \tag{1}$$

$$\mathbf{D} = \epsilon\mathbf{E} - j\gamma\mathbf{B} \qquad \mathbf{B} = \mu\mathbf{H} + j\mu\gamma\mathbf{E} \tag{2}$$

$$\mathbf{D} = \epsilon\mathbf{E} + \epsilon\beta\nabla \times \mathbf{E} \qquad \mathbf{B} = \mu\mathbf{H} + \mu\beta\nabla \times \mathbf{H} \tag{3}$$

where α, β, γ are chirality parameters. We introduce these various constitutive relations, compare them, and derive relations among them, including the wave equations for each. We then present arguments for the most useful forms of chiral media constitutive relations for the electromagnetic scattering community. Electromagnetic wave propagation in chiral media is discussed and possible applications of such media are explored.

INTEGRAL EQUATIONS FOR THE SCATTERING BY TWO AND THREE DIMENSIONAL INHOMOGENEOUS CHIRAL BODIES

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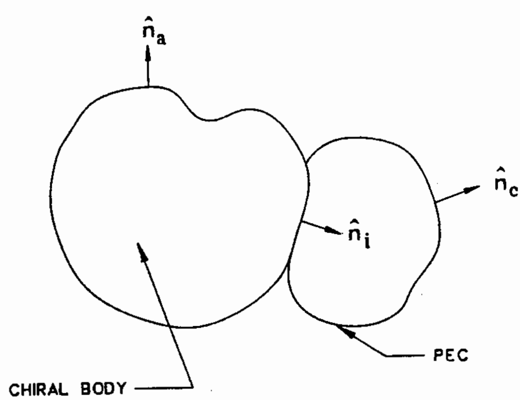
Columbus, Ohio 43212

Integral equations are obtained for the electromagnetic (EM) scattering by an inhomogeneous, isotropic chiral body. The chiral body is assumed to be in free-space and it can be attached to a perfect electric conducting (PEC) body. First, integral equations are obtained for a three-dimensional body with the help of the vector-dyadic Green's second identity and other vector-dyadic identities. The integral equations are expressed in terms of a volume integral with the electric field as the unknown and surface integrals where the normal components of the electric and magnetic fields (and the curl of these fields) are the unknowns. The free-space dyadic Green's function is used to simplified the analysis where the singularities of this function are properly taken into account. That is, in order to obtain integrable equations, slightly different expressions are obtained when the observation point is located on the surface of the chiral or PEC bodies.

Integral equations are also obtained for two-dimensional chiral and PEC bodies in terms of only two unknowns; namely, the z-components of the electric and magnetic fields, where the z-axis coincides with the axis of the two-dimensional bodies. The integral equations are expressed in terms of surface and line integrals and the two-dimensional free-space Green's function. The integral equations developed for the two-dimensional case are then numerically solved with the help of the moment method. Several examples are shown and compared with eigenfunction solutions. It is shown that the agreement between the two methods is very good.



Inhomogeneous chiral body attached to a PEC body

PLANE-WAVE SCATTERING FROM A SMALL CHIRAL SPHERE

Ismo V. Lindell* and Ari H. Sihvola
Helsinki University of Technology, Electromagnetics Laboratory
Otakaari 5A, SF-02150 Espoo, Finland

Quasi-static analysis similar to that leading to Rayleigh scattering expressions for dielectric and magnetic spheres is extended to spheres of chiral material. It is seen that the medium unites electrostatics to magnetostatics and the most natural way of considering the problem is in terms of wave fields, which are certain combinations of electric and magnetic fields.

The resulting expressions show that for incident plane-wave fields the chiral sphere can be replaced by an electric and a magnetic dipole, both with a cross-polarized component, which vanishes for nonchiral medium. The internal field for linearly polarized incident plane wave is constant and elliptically polarized with nonorthogonal electric and magnetic field components in general.

The resulting expressions are applied to forming effective material parameters for a medium with chiral spheres by constructing a mixing formula. They also have application for measuring material parameters in a resonator using a spherical sample of chiral medium by finding the shifts of different resonance frequencies.

EIGENSOLUTIONS FOR THE INTERFACE PROBLEM OF TWO CHIRAL HALF SPACES

Ari J. Viitanen *, Ismo V. Lindell,
Ari H. Sihvola, Sergei A. Tretyakov
Helsinki University of Technology, Electromagnetics Laboratory
Otakaari 5 A, SF-02150 Espoo, Finland

The problem involving a planar interface between two chiral media is considered. The characteristic waves propagating in a homogeneous chiral medium are known to be right-circularly and left-circularly polarized waves, possessing different propagation factors. In this presentation, the Silberstein wave-field decomposition of electromagnetic fields is applied to the reflection problem in chiral media. The eigenpolarization vectors in both media are determined and the corresponding reciprocal basis vectors are presented. Expressions for the reflection and the transmission dyadics are obtained from the continuity conditions of the tangential total electric and magnetic fields. Eigensolutions of the reflection dyadic for the interface of two chiral media are calculated from a dyadic eigenvalue equation.

The special case with upper medium isotropic and lower medium chiral is considered in more detail. Expressions for the eigenvalues of the reflection dyadic and the corresponding eigenpolarization vectors are calculated. Also, the limit cases for reflection from a half space with only small amount of chirality are studied. Finally polarization effects for a wave reflected from the chiral medium are considered in terms of TE and TM fields. At normal wave incidence similar reflection is found to occur as for the isotropic medium. The cross polarization effects caused by the chirality is found to appear at oblique wave incidence.

VECTOR CIRCUIT THEORY FOR ACHIRAL AND CHIRAL SLABS

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[1] Leningrad Polytechnic Institute, 195251, Polytechnicheskaya 29, Leningrad, USSR

This paper discusses modelling of isotropic achiral and chiral slabs by using vector circuits involving dyadic impedances and admittances and tangential field components. The analysis is based on the exact averaging method for the Fourier-transformed field equations of the slab. Then, by considering tangential electric and magnetic fields as voltages and currents, analogous vector circuits, such as equivalent two-port circuits, Thevenin and Norton circuits and T and Π circuits, are given for achiral and chiral isotropic and homogeneous and nonhomogeneous slabs. These vector circuits are most appropriate when calculating propagated and reflected fields for general excitation. In addition, different approximations related to slabs thin either in wavenumbers in the normal or in transversal directions or to slabs with different propagation constant ratios are considered. A case when a slab can be simulated by a sheet is also discussed. The results obtained can be useful in many practical situations, for example, for multilayered structures with small differences in parameters of the layers, or, vice versa, for slabs with contrast parameters.

REFLECTION AND TRANSMISSION IN CHIRAL MULTILAYER SLABS

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[1] Leningrad Polytechnic Institute, 195251, Polytechnicheskaya 29, Leningrad, USSR

In this paper reflection and transmission dyadic coefficients for multilayered chiral sturtures are studied. Explicit formulas for the coefficients are derived using vector circuit method (S.A.Tretyakov, M.I.Oksanen, report 50, Electromagnetics Lab., Helsinki Univ. of Technology). The new approach allows one to handle arbitrary angles of incidence and arbitrary polarization states simultaneously. The analysis covers co- and cross-polarized reflected and transmitted waves. As examples, numerical results for reflected and transmitted fields in single- and multilayered chiral slabs are calculated. Typical reflection and transmission curves are shown in Figure 1.

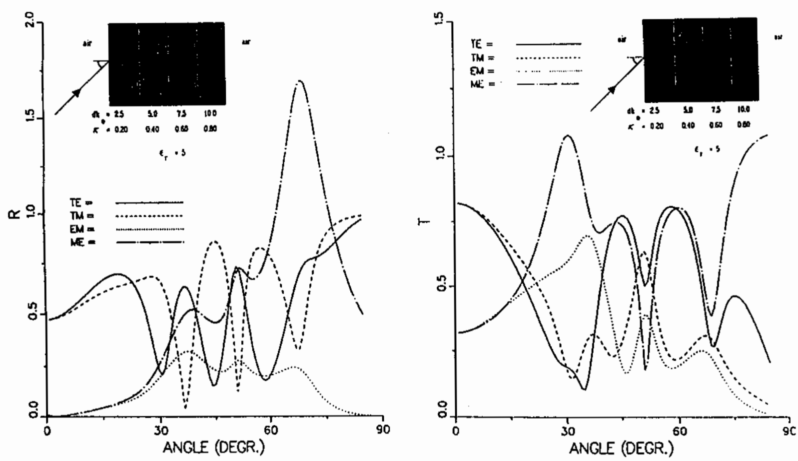

Figure 1. Absolute values of the reflection and transmission coefficients for a four-layer chiral slab. TE and TM stand for the TE- and TM-waves, respectively, and EM and ME are cross-polarized components indicating coupling from the TE-wave to the TM-wave, and vice versa.

Tuesday AM
URSI-B Session 31
Guiding Structures I

Chairs: Stan J. Kubina, Concordia University; Motohisa Kanda, National Bureau of Standards

Room: W-102 *Time*: 8:15-12:00

SOLVING MICROSTRIP DISCONTINUITY PROBLEMS USING AN EMBEDDED TECHNIQUE

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In analyzing planar microstrip structures, a spatial-domain integral equation formulation with sub-sectional rectangular pulses as the basis functions provides a simple yet versatile approach. A full 2D current can be used wherever needed without incurring additional numerical complexity. Thus, this approach is well-suited for treating non-simple discontinuities such as L-bends, patches, or interdigited capacitors. However, since the conventional spatial-domain integral equation solver yields only the current on the microstrip, additional post-processing is needed to obtain the scattering parameters of a given junction.

A typical post-processing method for extracting the S-parameters from the computed current is to use transmission-line modeling on the current over a portion of the strip away from the junction (D. Wu and D. Chang, URSI Abstracts, p. 37, June, 1989). The strip at each port is artificially made long (3 to 4 wavelengths) to ensure dominant-mode propagation over the center portion of the strip. Although this method has been shown to yield accurate results, the overall process can be time-consuming. Moreover, the extra long strip needed at each port can present a problem for multi-port structures because the total number of unknowns may exceed the computational capacity of a workstation.

To eliminate these obstacles, we present a method where the transmission-line modeling is invoked inside the spatial-domain integral equation solver. The guided wavelength on each strip, which can be precomputed easily for a given strip width-to-substrate height ratio, is assumed to be known. The current over each extended strip is modeled by two unknowns representing forward and backward propagating waves. By applying orthogonality, the coupling matrix associated with the integral equation is modified in such a way that the group of unknown coefficients representing the current over a given strip is now replaced with two unknowns. With straightforward matrix manipulations, these two unknowns along with the coefficients for the remaining structure can be solved directly. This method not only preserves the versatility and the simplicity of our original spatial-domain integral equation solver, it also requires minimal modifications. The reduction in the total number of unknowns implies that complex structures may now be analyzed on a finite-capacity workstation. The utility of this method will be demonstrated by several nonsimple discontinuities. A comparison between this embedded method and the post-processing method for obtaining the S-parameters will be presented. The applicability of this method to large circuit modeling will also be discussed.

THE ENERGY DECAY IN PLASMA WAVEGUIDE

Hao-Ming Shen
Harvard University
and
Hsueh-Yuan Pao*
Watkins-Johnson Company

Abstract

It has been shown that there is some possibility to use a "Plasma Waveguide" to transfer the electromagnetic energy in upper space[1]. Such waveguide consists of a cylindrical vacuum core surrounded by a plasma cladding medium. The analysis and survey show that:

(1) There exists guided modes with wide frequency band;

(2) The single mode operation is also possible without high frequency limitation; and

(3) Such waveguide can be generated by a hollow-laser beam with modest energy[2].

In the first model of the plasma waveguide, the plasma cladding is assumed transversely extended to infinity. Therefore, the guided modes are loss free. If the thickness of the plasma cladding is finite, there will be a energy loss from the outside surface of the plasma cladding. This paper is to analyze a plasma waveguide with finite thickness and calculate the coefficient of the energy decay in terms of the thickness.

Reference

[1] Hao Ming Shen, "Plasma Waveguide", submitted for publication.
[2] APS Study, Science and Technology of Directed Energy Weapons, Chapter 4.2, Rev. Mod. Phys. Vol. 59, No. 3, Part II, July 1987.

* The speaker.

ON THE LINEAR PROPAGATION OF SELF-FOCUSSING BEAM PROFILES WITH AND WITHOUT EXTERNAL LENSING

Partha P. Banerjee* and Chin-Ru Lin

Department of Electrical Engineering, Syracuse University
Syracuse, N.Y. 13244

ABSTRACT

Some beam profiles leading to self-focussing during propagation in a linear medium have been earlier reported (P.P. Banerjee and T.-C. Poon, 1989 APS/URSI meeting), and a simple power series method employed to determine the point of focus. In this talk, we provide a more accurate description of the focal point by directly using the Fresnel diffraction formula for *modified* Gaussian beams. The results reduce to previously reported results for suitable limits.

We thereafter subject these modified Gauusian beams to external focussing using converging lenses. Similar to focal shifts in Gaussian beams and focussed annular beams (see, for instance, T.-C. Poon, Opt. Comm. p.401, 1988), we observe that for a certain class of modified Gaussians, there is only one point of focus, albiet different from the focal point of the lens. This is true for modified Gaussians which do not linearly focus by themselves, and also for some that possess a linear focus without external lensing. For certain other classes, we observe two points of focus. The focussing, in each case, is accurately predictable on the basis of the Fresnel diffraction formula, and agree well with numerical simulations using Fast Fourier Transform techniques.

LOCALIZED ENERGY PULSES IN OPTICAL FIBER WAVEGUIDES

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and

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The bidirectional spectral representation [I. M. Besieris, A. M. Shaarawi and R. W. Ziolkowski, J. Math. Phys. 30, 1254 (1989)] yields a rich class of exact solutions to the scalar wave equation that describe localized, slowly decaying transmission of wave energy. The practical realizability of launching such pulses has been demonstrated [R. W. Ziolkowski, Phys. Rev. A 39, 2005 (1989); R. W. Ziolkowski, D. K. Lewis and B. D. Cook, Phys. Rev. Lett. 62, 147 (1989)] in the case of acoustic directed energy pulse trains. Similar solutions are feasible in geometries involving boundaries [A. M. Shaarawi, I. M. Besieris and R. W. Ziolkowski, J. Appl. Phys. 65, 805 (1989)].

The bidirectional decomposition has been applied to a fiber optical waveguide and the possibility of synthesizing localized solutions that can propagate only with local variations has been investigated. These "almost nonspreading" solutions are fundamentally distinct from purely solitary wave packets propagating along nonlinear fibers.

For linearly polarized modes, solutions will be presented for two types of source spectra. The nature of these solutions, which are similar to focus wave modes and splash waves, respectively, will be examined in detail, and the distances along the guide for which they exhibit essentially no decay will be quantified. The feasibility of a practical implementation of such solutions will be discussed and remarks will be made regarding other relevant spectra. A brief assessment will also be made of the effects of dissipation and dispersion in the core and the cladding.

Present address: Department of Engineering Physics and Mathematics, Faculty of Engineering, Cairo University, Giza, Egypt.

Radiation Characteristics of Characteristics of NRD Guide

Ching-Kuang Tzuang*, Ching-Cheng Tien* and S. T. Peng**

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and Center for Telecommunications Research
National Chiao-Tung University
Hsinchu, Taiwan, Republic of China

** Electromagnetics Laboratory
New York Institute of Technology
Old Westbury, NY, USA

The radiation from a perturbed non-radiative dielectric waveguide was suggested to be used as a new type of leaky-wave antennas (Oliner, A. A., et. al., IEEE MTT-S Internatioal Symposium Digest, 1985, pp. 619-622). The perturbed structure is formulated rigorously as a three-dimensional bouundary-value problem by the method of mode matching, taking into account the polarization couplings through which the leakage of energy occurs. The effects of structure parameters are systematically evaluated over a wide range of frequency; in particular, perturbations with reflection and inversion symmetries are examined, including their effects on the phase and decay constants, as well as the field orientations.

A TOPOLOGICALLY DISPERSIVE OPTICAL TRANSVERSAL FILTER USING PLANAR WAVEGUIDES WITH PERIODIC SERRATIONS

Partha P. Banerjee[1] & Monish R. Chatterjee[2*]

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Syracuse, N.Y. 13244

[2]Department of Electrical Engineering, SUNY at Binghamton
Binghamton, N.Y. 13901

ABSTRACT

Fiber-optic delay line filters for optical signal processing have been demonstrated for various applications, including transversal, FIR, and IIR filters, and for encoding and decoding. Conventionally, the processing delay for such devices is estimated from the propagation delay of the fibers.

We propose here a planar waveguide structure with topological dispersion introduced by periodic serrations. These periodic serrations may be either left vacant, or implanted with a dielectric of a different refractive index. Our analysis of the dispersion characteristics of such a geometry follows closely along the lines of an earlier investigation in a parallel problem in the acoustic domain (Banerjee and Korpel, J. Acoust. Soc. Amer. 80 (1986)). In the latter work, it was shown that by varying the duty cycle of the corrugation in the wall enclosing a fluid, the dispersion characteristics for propagating bulk waves parallel to the corrugation could be altered.

An alternative approach to the problem is to consider the serrations to be the equivalent to waveguides of dimensions different from that of the nonserrated sections. Hence, it is possible to construct the overall transfer function for such a cascade and thus calculate dispersion from a knowledge of the amount of pulse spreading.

In the above analysis, we have assumed no modal and/or chromatic dispersion effects.

ANALYSIS OF LEAKY MODES OF INTEGRATED DIELECTRIC OPTICAL WAVEGUIDES

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The propagation regions of integrated dielectric optical waveguides have been thoroughly explored in the past few years. Though the bound modes of these waveguiding structures are well understood, the leaky modes, those that are significant to inter–device coupling, have been sadly neglected.

Analysis of the leaky modes for the integrated optical waveguides can be accomplished by using a well–known equivalent polarization EFIE:

$$\vec{e}(\vec{\rho},\zeta) - (k_c^2 + \tilde{\nabla}\tilde{\nabla}\cdot)\int_{CS} \frac{\delta n^2(\vec{\rho}')}{n_c^2} \overleftrightarrow{g}(\vec{\rho}|\vec{\rho}',\zeta)\cdot\vec{e}(\vec{\rho}',\zeta)\, dS' = \vec{e}^{\,i}(\vec{\rho}',\zeta)$$

where $\overleftrightarrow{g}$ is the Hertzian potential Green's dyad for the tri–layered background media, $\vec{e}$ is the electric field supported by the waveguide for a propagation constant of ζ, $\delta n^2(\vec{\rho}')$ is the contrast between the waveguide core and the cover region of index n_c, and CS is the cross–section of the waveguide core. The components of the Green's dyad are, as with all exact formulations in layered media, Sommerfeld integrals in terms of the spectral variables.

The above integral equation can be decoupled into transverse and axial parts. The axial field of the integrated dielectric optical waveguide is a function of the transverse fields, hence we need only find the transverse fields of the optical waveguide. Based upon prior efforts by the authors in the similar but simpler case of microstrip transmission lines, it is expected that full–domain basis functions can be used to great effect in determining field profiles and propagation constants for these leaky modes. A full complex–plane integration technique can also be used to evaluate the Green's dyadic kernals. This second approach also has the advantage of not needing apriori knowledge of integration paths in the spectral transform plane.

RIGOROUS EQUIVALENT NETWORK REPRESENTATION FOR INDUCTIVE DISCONTINUITIES IN OVER-MODED RECTANGULAR WAVEGUIDE

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and Technology Centre
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An equivalent network representation is developed to describe the scattering from inductive discontinuities in over-moded rectangular waveguide. The network is developed following a rigorous procedure and its elements are given in analytic form. Solutions are derived for both zero thickness windows and strips. The results obtained are valid for arbitrary obstacle/aperture width and offset. The effect of different media on either side of the discontinuity can also be evaluated. The network developed can be used in single-mode as well as in an over-moded environment.

A procedure is followed which leads to a description of the mode-coupling in terms of a shunt matrix. The particular form of the equivalent network arises from a suitable re-definition of the modal currents: a key feature that enables the rigorous closed-form solution of the fundamental integral equations. Analytic expressions involving a double integration are obtained for the elements of the coupling matrix. The same network form is shown to apply to both the inductive aperture and obstacle.

Numerical comparisons with known results are presented for the values of the shunt inductance of windows and single strips in single mode waveguide. The rapid convergence of the network representation with increasing mode number is demonstrated. As an example of an over-moded situation, computations are carried out for the power division between the first two waveguide modes as a function of obstacle/aperture geometry. In addition, numerical results are presented for the reflected power in a strongly over-moded structure.

GSM OF WAVEGUIDE DISCONTINUITIES WITH ARBITRARY CROSS-SECTION.

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Grupo de Electromagnetismo Aplicado y Microondas.
E.T.S.I. de Telecomunicación. U.P.M.
E28040 Madrid. Spain.

Description of discontinuities between waveguides of arbitrary cross-section by means of the Generalized Scattering Matrix method (GSM) requires accurate expressions for the fields of fundamental and higher order modes in each waveguide.

It has been proved that Schelkunoff method provides an accurate solution of fields inside homogeneous waveguides with arbitrary cross-section. Another important advantage of this method is that the field can be expressed as a superposition of a few simple functions. This method has been applied to the characterization of truncated-circle waveguide (Nava E. and Rebollar J.M., URSI Stockholm, 1989).

A computer program has been developed to obtain the GSM of discontinuities between two different truncated circle waveguides. Once the GSM of one single discontinuity is obtained, the analysis of more complex structures (as for example, polarisers on circular waveguide) is easily implemented by well known procedures (Patzlet H. and Arndt F., IEEE Tr. MTT, vol 30 pp. 771-776). This technique has been applied to the design of circular polarisers and a good agreement between numerical and experimental results has been obtained.

ANALYSIS OF WAVE PROPAGATION IN CURVED AND TWISTED DIELECTRIC OPTICAL WAVEGUIDES USING VOLUME EQUIVALENT CURRENTS

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Department of Electrical and Electronics Engineering
Bilkent 06533 Ankara Turkey

It is well-known that a curved optical waveguide looses its wave energy through radiation. For the fundamental mode of optical fibers, this curvature loss can be computed through substitution of the core region by volume equivalent currents radiating in an infinite medium (Snyder and Love, Optical Waveguide Theory, Chapman and Hall, 1983). So, the optical fiber is treated as a dielectric antenna.

In this talk, the same procedure will be extended to multimode fibers and it will be shown that for weakly guiding fibers the curvature loss is independent of polarization for large bend radius.

Optical fibers are sometimes wound helically due to its circular birefringence property. In a helical fiber, there is helical loss arising from the periodicity of the geometry in addition to the curvature loss. Both of these loss mechanisms are described by the dielectric antenna model mentioned above (Snyder and Love, Electronics Letters, pp. 1109-1110, 8th Oct. 1987; also, Altintas and Love, Optical and Quantum Electronics, to be published). The extension of the volume equivalent currents to "multimode" helical fibers and their polarization properties will also be discussed in this presentation.

Tuesday AM

Joint AP-S, URSI-B Special Session 32

Superconductive Material Characterizations and Applications

Chairs: Kenneth K. Mei, University of California at Berkeley; Frederick M. Tesche, Consultant

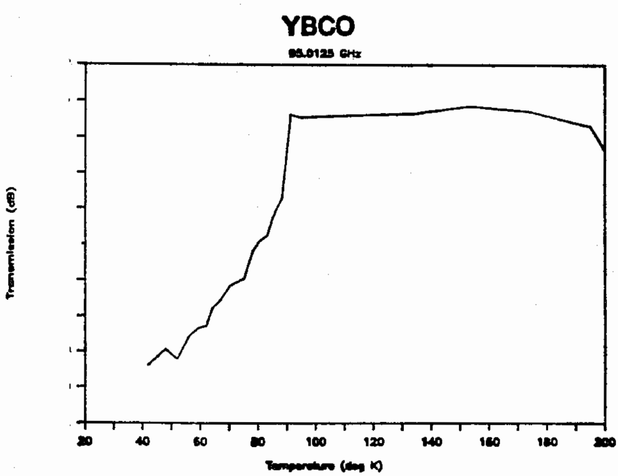
Room: W-105 *Time*: 8:15-11:40

8:20	**Microwave and Millimeter Wave Characterization of High Temperature Superconducting Thin Films** Alan D. MacDonald, Stuart A. Long*, Jeffery T. Williams, David R. Jackson, University of Houston	AP-S
8:40	**W-Band Characterization of Thin Film Superconductors** Dr. Rick L. Moore*, R. Moroz, K. Zhang, B. S. Kwak, A. Erbil, Georgia Institute of Technology	158
9:00	**A General Analysis of the Slow Wave Propagation Along a Superconducting Stripline** David Nghiem, Jeffery T. Williams*, University of Houston	AP-S
9:20	**Superconducting Antennas** Robert C. Hansen*, R. C. Hansen Inc.	AP-S
9:40	**The Radiation Efficiency of a Small Dipole Antenna Made from a High Temperature Superconductor** Robert J. Dinger*, David J. White, Naval Weapons Center	AP-S
10:00	**Coffee Break**	
10:20	**Propagation Properties of a Superconductive Stripline** Guo-Chun Liang*, Y. W. Liu, Kenneth K. Mei, University of California at Berkeley	AP-S
10:40	**Analysis of the Propagation of Superconductor Coupled Microstrip Lines** F. Huret*, D. Kinowski, CHS Equipe electrmagnetismu Des Circuits; C. Seguinot, P. Kennis, P. Pribetich, Univ. Des Sciences ET Tech. De Lille	159
11:00	**New Analytical Model of Superconducting Coplanar Lines for MMIC's** D. Kinowski*, CHS Equipe electrmagnetismu Des Circuits; C. Seguinot, P. Pribetich, P. Kennis, Univ. Des Sciences ET Tech. De Lille	160
11:20	**Surface Resistivity Measurements of Superconducting YBCO Helices at UHA** Donald R. Bowling*, Robert J. Dinger, Naval Weapons Center; Neil M. Alford, ICI Advanced Materials	AP-S

W-BAND CHARACTERIZATION OF THIN FILM SUPERCONDUCTORS

R.L.Moore* and R.Moroz Ga Tech Research Institue,
K.Zhang.B.S.Kwak, and A.Erbil Ga Tech Department of Physics
Georgia Institute of Technology, Atlanta Georgia

Superconducting thin films of $YBa_2Cu_3O_{7-x}$ and Thallium substitued thin films were successfully grown on yttria-stabilized zirconia and sapphire substrates by using metalorganic chemical vapor deposition techniques (Conference on Science and Technology of Thin Film Superconductors,Nov.14-18,1988 Colorado Springs). A free space focused lens system has been used to measure the complex transmission coefficient of those films at frequencies of 75-100 Ghz. A Hewlett-Packard 8510 system was used as source and receiver. Measurements at temperatures of 20-300 ^{0}K are reported for film thicknesses near 1 micron. Figures below show example transmission data for measurements of the 1-2-3 and thallium films. Data to be reported will include: YSZ and Sapphire dielectric properties and surface impedance of the superconductors as functions of frequency and temperature.



Analysis of the propagation of superconductor coupled microstrip lines.

F.HURET, D.KINOWSKI, C.SEGUINOT, P.KENNIS, P.PRIBETICH

CHS Equipe Electromagnetisme des Circuits UA CNRS 287; 59655 VILLENEUVE D' ASCQ CEDEX

The interest for gigabit-rate speed logic is growing and currently the designers have to deal with interconnection problems due to the crosstalk phenomena of picosecond pulses. Such problems are also encountered in analogic monolithic microwave integrated circuits in which interconnections must be considered as transmission lines. So the development of these very high-speed-logic (LSI and VISI) and high-freqency analogic (MMIC) circuits is dependent on the knowledge and minimization of these spurious propagation and coupling effects. In order to reduce the influence of these spurious phenomena, we propose to substitue the classical metallic strip by superconductor strips. For that, we propose in this communication to compare the performance of interconnections laid on insulating substrate and MIS structures for several kind of strips: perfect conductor strips, lossy conductor strips, low critical superconductor strip and new high temperature T_c superconductor strips (YBaCuO). These comparisons are made for two structures with similar geometrical characteristics but laid on different substrates (figure 1). In order to show the effects, the time-domain analysis is done in four steps, which may be described as follow:

a) determination of propagation characteristics (SDA) including the nature of the strip.

b) circuit analysis (figure 2) in the frequencial domain.

c) determination of time-domain voltages (FFT).

d) calculation of important characteristics such as rise time, delay time and crosstalk.

Concerning the point (a), we must modified the classical Spectral Domain Approach by using the complex boundary condition based on the surface impedance. As example, we give (figure 3) the influence of the superconductor on the propagation parameters of the even mode of coupled microstrip lines. After that, we can determine by using the time domain analysis time domain results (figure 4).

At the conference, we will present the main steps of the time domain analysis and more precisely, the determination of the propagation characteritics of the fundamental modes showing in an engineering purpose the influence on the crosstalk phenomena of several kinds of strips, perfect, lossy metallic strips and low critical and high critical temperature superconductor strips.

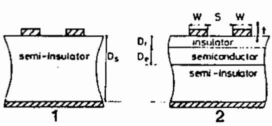


Fig. 1 *Cross-section of analysed lines*

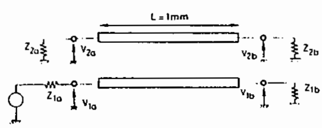


Fig. 2 *Analysed coupled-line circuit*

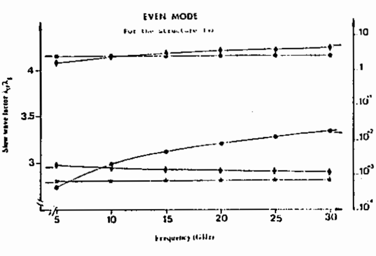


Fig. 3

- Superconductor line : NbN, T=4°K, t=150 Å
- Metallic line : σ=2.10⁵ S/cm, t=2 μm
- Perfect line : σ-> ∞ , t-> 0

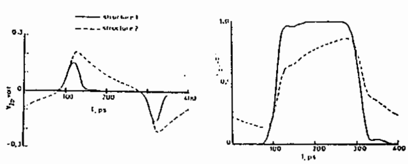


Fig. 4 *Time-domain results in capacitive loading case*

NEW ANALYTICAL MODEL OF SUPERCONDUCTING COPLANAR LINES FOR MMIC's.

D. KINOWSKI , C. SEGUINOT , P. PRIBETICH , P. KENNIS

Centre Hyperfréquences et Semiconducteurs
Equipe Electromagnétisme des circuits
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USTL FLANDRES-ARTOIS
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When MMIC's are used at high frequencies , interconnections must be regarded as propagating lines involving delay time , attenuation and shape modification of waveform. Propagation phenomena on MIS or Schottky contact coplanar lines are now well known . These kinds of structures (fig 1) display the following propagation characteristics : a high slowing factor and a low characteristic impedance . Moreover the reduction of transversal strip size, needed in monolithic applications , leads to high metallic losses when normal conductors are employed. In this mind , superconductors seem to be a very attractive way to overcome this drawback and so to realise high frequency MMIC's. Numerical simulations , such as the Modified Spectral Domain Approach , are heavy-built methods not suitable to computer aided design and to engineering purpose. The aim of this study is to developp an analytical model of the Schottky or MIS superconducting coplanar lines after testing and comparing its results to the results obtained by the Modified Spectral Domain Approach [1]. Up to now , to our knowledge , a model for this kind of structure with superconducting strips has never been proposed in the litterature. The analytical model is shown on figure 2 , where the superconductor is modelled in a phenomenological point of view through the simple theory : the Two-fluid model . Some results , about the slowing factor and the attenuation , compared to M.S.D.A.'s ones are presented on figures 3 and 4. Our numerical simulation shows that a proper set of geometrical and physical parameters makes it possible to increase , through the kinetic inductance of the line , both the slowing factor and the characteristic impedance. At the conference , we will detail this new model of superconducting coplanar lines and present results for different kind of superconductors : the old NbN and the new YBaCuO .

[1] KINOWSKI D. , HURET F. , PRIBETICH P. , KENNIS P. :" *Spectral domain analysis of coplanar superconducting line laid on multilayered GaAs substrate.* " Electronics Letters , vol 25 , n 12 , June 1989 , pp 788-789

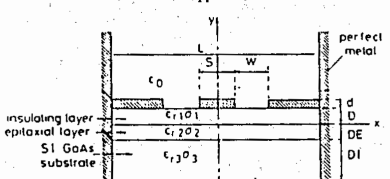
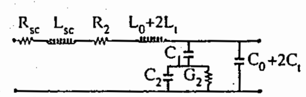


figure -1-

$W = S = 5\mu m$, $D = 0{\cdot}2\mu m$, $DE = 0{\cdot}6\mu m$, $L = 500\mu m$, $\epsilon_1 = \epsilon_2 = \epsilon_3 = 13$, $\sigma_1 = 0$, $\sigma_2 = 60\Omega^{-1}cm^{-1}$, $\sigma_3 = 10^{-3}\Omega^{-1}cm^{-1}$, $DI = 100\mu m$



Model for MIS and Schottky contact coplanar line

figure -2-

Rsc and Lsc model the influence of superconductors

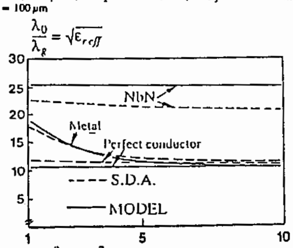


figure -3-

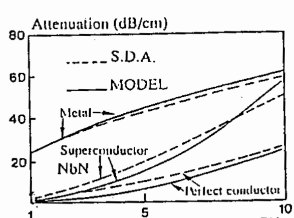


figure -4-

Tuesday AM
URSI-B Session 33
Antenna Analysis II

Chairs: Michael A. Morgan, Naval Postgraduate School; Sharad Laxpati, The University of Illinois at Chicago

Room: W-106 *Time*: 8:15-12:00

CYLINDRICAL HARMONIC BASED ANALYSIS OF A DIELECTRIC LOADED TOP-HAT MONOPOLE ANTENNA

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Naval Postgraguate School, Monterey, CA 93943

Felix K. Schwering
Attn: AMSEL-RD-C3-TA1
Center for C^3 Systems, Fort Monmouth, NJ 07703

An eigenfunction expansion method is presented for computing the currents on a dielectric loaded top-hat monopole antenna radiating into the half-space over an infinite perfect electric conductor (PEC) ground plane. The antenna is enclosed by adding a second, parallel ground plane, as illustrated in Figure 1. This approximation allows the fields to be represented using cylindrical harmonic expansions in each of three subregions between the ground planes. Coefficients of these expansions are found by enforcing $E_{tan} = 0$ along all PEC surfaces as well as enforcing continuity of the tangential fields at the interfaces between the cylindrical subregions.

Problems encountered in developing the method are considered. Example computations are presented with application towards designing enhanced bandwidth structures through use of lossy dielectric loading.

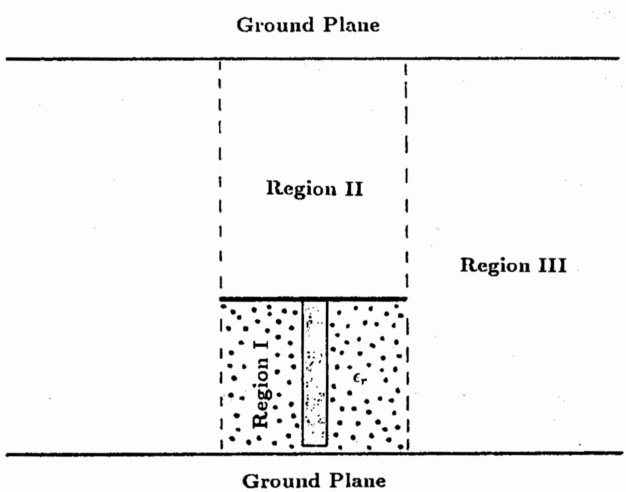

Figure 1 Loaded Top-Hat Monopole Between Ground Planes

RADIATION FROM A CIRCULAR LOOP ANTENNA IN A PARALLEL PLATE WAVEGUIDE

Hassan A. N. Hejase
and
Heath L. Duncan

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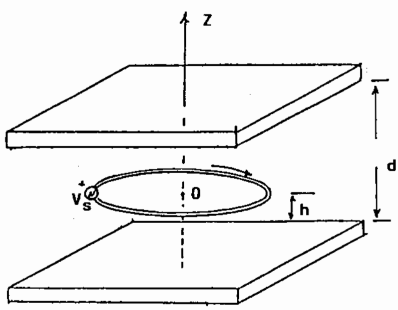
Lexington, Kentucky 40506-0046

Radiation from a circular wire loop antenna placed between two parallel conducting plates of infinite extent is studied. The loop axis is taken perpendicular to the conducting plates. Assume that the loop is driven by a delta-gap voltage source. Image theory is used to replace the plates with an infinite array of image loop antennas. The integro-differential equation for the current distribution on the wire loop array is solved by the method of moments. Plots of the far field pattern and directive power gain are presented. Then, a comparison with the radiation properties of a loop in free space and a loop over a ground plane is performed. An answer to whether much larger field strengths would be obtained by the proposed configuration is provided.



A MIXED-DOMAIN APPROACH FOR ANALYSIS OF COMPLEX ANTENNAS

D. -S. Wang* and L. N. Medgyesi-Mitschang
McDonnell Douglas Research Laboratories
P. O. Box 516
St. Louis, MO 63166

The electromagnetic characterization of complex surface-conformal antennas embedded in a dielectric layer is very difficult. The presence of a dielectric layer introduces various wave species responsible for surface waves propagating along the air-dielectric boundary and space waves radiating outside. For relatively simple microstrip antennas, one can use the dyadic Green's function formulation following the method of Ohm-Rayleigh. Whenever, the embedding dielectric layer is non-uniform (inhomogeneous), or the geometry of the antenna is irregular, the foregoing formulation is computationally intractable.

In this presentation, we describe a mixed-domain approach that is tractable to complex antennas with embedding dielectric layers. For purposes of this exposition, we restrict the focus to antennas having rotationally symmetry. The embedding dielectric layers need not be uniform, but have azimuthal invariance. In the current approach, the complexity of the antenna and the dielectric interface in the vicinity of the antenna will be treated using the method of moments with sub-domain basis functions. Outside the neighborhood of the antenna, the surface currents are expanded in terms of a set of new entire-domain basis functions modeling the effects of the surface waves propagating along the interfaces of the air-dielectric and the dielectric-ground plane. The surface in the vicinity of the antenna is the sub-domain region and the remaining surface outside the antenna is the entire-domain region. The electromagnetic fields near the interface of the two regions are matched to ensure the continuity of the solution. The effectiveness of this approach will be illustrated using previously published data.

THE ELECTROMAGNETIC CHARACTERISTICS OF LOOP ANTENNAS POSITIONED COAXIALLY IN CYLINDRICALLY STRATIFIED MEDIA

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and

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A determination of the electromagnetic characteristics of loop antennas in cylindrically stratified media is useful in such areas as biomedical engineering, fibre-optics, and antenna design.

This paper presents a rigorous analytical formulation for the input impedance and radiation characteristics of a loop antenna positioned coaxially in a multiply layered cylindrically stratified media. The loop, as shown in Figure 1, is modelled as a $\sum_{i=1}^{n} \cos n \phi \, \delta(z)$ electric current distribution on the material interface.

The formulation, based upon Debye potentials, yields exact expressions for all electromagnetic field components in a form similar to Sommerfeld integrals. The thin wire model is employed with a rectangular voltage pulse to predict the input impedance while closed form expressions obtained via the steepest descent techniques are used to compute the radiation characteristics.

Verification of the formalism is accomplished by particularizing the general geometry to the case of a loop antenna on dielectric cylinder. Comparisons are made between the general and special case to verify input impedance and radiation characteristic prediction.

Finally, numerical results are provided for a number of cases where the effect of dielectric constant and layer thickness is illustrated.

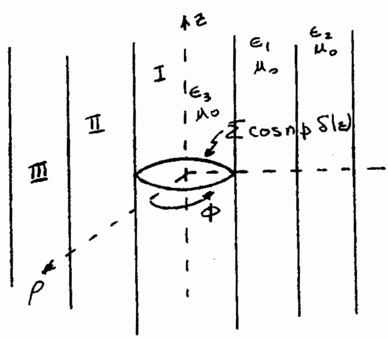

figure 1

THE RANGE OF INFLUENCE OF GROUND SYSTEM LOSS ON ANTENNA IMPEDANCE

T. L. Simpson*, Feng Gao, Electrical and Computer Engineering Department, University of South Carolina, Columbia, SC 29208

Clark Robertson, Electrical and Computer Engineering Department, Naval Postgraduate School, Monterey, CA 93943

To establish a basis for developing an improved method for computing ground system losses we reconsider the problem of an electrically-small monopole antenna over a finite disc of perfect electrical conductivity (PEC) and of radius ρ_1 lying on the earth's (assumed planar) surface. For $\rho > \rho_2$, the surface is also covered by a PEC sheet, so that the earth is exposed within an annular slot. Using the method of moments together with cylindrical mode expansions in the three cylindrical regions, $\rho < \rho_1$, $\rho_1 < \rho < \rho_2$, and $\rho < \rho_2 < \infty$, theoretical solutions are obtained for the antenna input impedance. By allowing ρ_2 to approach infinity, a practical definition of the radial range of influence of the finite conductivity of the earth is obtained.

In the design of large buried-wire ground systems for LF and VLF antennas, it is essential to know the radial range of influence, $\rho < \rho_\infty$, of the unwired earth on the input impedance, since increasing the extent of the wired system beyond this point can not, by definition, alter antenna performance per se. This is not to say that path losses are not important in point-to-point communication systems, but rather that there is a finite limit to the radial range of influence of earth loss for an antenna of a certain size operated at a certain frequency. H. A. Wheeler (Proc. I.R.E, 1947, 1959) and J. R. Wait, et. al. (J. appl. Physics, 1954; Wireless Engineer, 1955) considered this problem. Wheeler proposed the radianlength as the practical boundary between antenna and environment, and Wait, using an approximation based on the compensation theorem and the perfect-conductivity H-field, showed that the input resistance clearly approached its asymptotic limit not far beyond the radianlength. Using a rigorous analytical technique, it is possible to observe that the resistance increment decays somewhat more rapidly with radius than previously estimated and to establish the asymptotic behavior as well.

The practical application of this work to the analysis of VLF ground systems with the method of moments. It is expected that by using a quasi-static Green's function within the wired and unwired regions, $\rho < \rho_\infty$, and a semi-infinite boundary element to account for the small residual end effect, considerable improvement in the speed and accuracy of ground system computations may be obtained.

ANALYSIS OF METAL-STRIP-LOADED MULTI-LAYER DIELECTRIC ANTENNAS

J. A. Encinar
Universidad Politecnica de Madrid

The aim of this communication is to apply the well known mode matching technique to the analysis of metal-strip-loaded multi-layer dielectric antennas. The structure is shown in figure 1. The theory takes into account the thickness of the metal strips, and it is accurate when applies to infinite extent structures. Finite width antennas are analyzed by using mode matching together with the effective dielectric constant (E.D.C.) method. The method has already been applied to the same structure with only one dielectric layer (J.A. Encinar, IEEE AP-S, San Jose, 1989), and now is generalized to multilayer structures.

The proposed method is based on a modal expansion representation of the fields in each region. Boundary conditions at each interface are imposed and, after some algebraic manipulations, a matrix equation is obtained. The equation is solved for the complex eigenvalue $\beta_e - j\alpha$. β_e is the phase constant of the mode in the structure and α is the rate of leakage. From α and β_e, the fields in any region are computed. A more expanded description of the method, and some results, to check its validity, will be given in the oral presentation.

As a final remark, the proposed technique provides a useful tool for accurate analysis and design of multi-layer planar leaky-wave antennas. As an example, the technique can be used together with an optimization procedure for very low sidelobe and narrow beam antenna design (J.A. Encinar, M. Guglielmi, A.A. Oliner, URSI. Syracuse, N.Y., 1988).

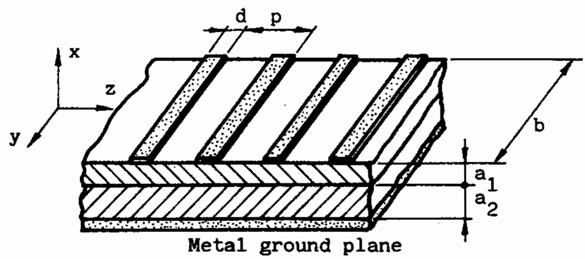

Figure 1

WIENER-HOPF ANALYSIS OF THE RADIATION FROM A FINITE LENGTH MULTIFILAR HELIX FED BY A CIRCULAR WAVEGUIDE

Carlos A. Fernandes *, Afonso M. Barbosa

Centro de Análise e Processamento de Sinais, and
Departamento de Engenharia Electrotécnica e de Computadores,
Instituto Superior Técnico
Av. Rovisco Pais, 1096 Lisboa CODEX, Portugal

A finite length multifilar helix excited by the circular waveguide TE_{11} wave with circular polarization, can show both an improved circular polarization and an improved pattern symmetry when compared to the conventional application of the monofilar helix (R.G.Vaughan and J.B.Andersen, *IEEE Trans. AP*, Vol.AP-33, 10-20, 1985).

The purpose of this work is to analyse this structure using the Wiener-Hopf formulation, and to investigate the nature of the reflected waves at the open end of the finite length helix. In the mathematical model the multifilar helix is replaced by the "sheath helix" model, and both the waveguide and helix are assumed to have the same diameter. This problem can not be solved exactly using the Wiener-Hopf formulation. A good approximation of the solution is obtained in this work decomposing this problem into two canonical problems, each one amenable to an exact Wiener-Hopf solution:

a) A semi-infinite sheath helix fed by a semi-infinite circular waveguide that carries a circularly polarized TE_{11} wave; the solution for this problem has been obtained before (C.A.Fernandes and A.M.Barbosa, submitted to *IEE part H* in 1989).

b) A semi-infinite sheath helix excited by the discrete modes that are launched in the previous structure.

In a previous work (C.A.Fernandes, A.M.Barbosa, to appear in *JEWA* in 1990) it has been shown using an approximate method that the fields near the structure a) can be interpreted as a superposition of a continous spectrum wave and two main discrete modes, corresponding to a real root and to an improper complex root of the modal equation. The contribution of the space wave over the sheath helix surface becomes significantly less important at the onset of the discrete modes, which is typically only a fraction of the wavelength away from the waveguide open end. This allows to neglect the influence of the space wave of problem a) over the surface of the helix in problem b), which greatly simplifies its solution.

The solution of the original problem is obtained as a combination of the solutions of problems a) and b). The validity of the procedure is discussed. Calculated radiation patterns are shown to agree well with measured patterns.

CHARACTERISTICS OF AN OFFSET YAGI-UDA ANTENNA IN A GRID CORNER REFLECTOR

C L LAW AND EDWARD K N YUNG
DEPARTMENT OF ELECTRONIC ENGINEERING
CITY POLYTECHNIC OF HONG KONG
KOWLOON, HONG KONG

ABSTRACT

Nowadays most of the TV programs are broadcasted in either vertically polarized or horizontally polarized wave. However, with the recent introduction of new digital features such as digital stereo sound, the accuracy for the reception of the wave is far more important. In order to improve the accuracy of digital reception, circularly polarized wave is transmitted because it provides a better noise performance for its multipath fading. As a result, a simple and robust circularly polarized receiving antenna should be developed. Consequently, the objective of this paper is to introduce a simple method to convert the traditional household linearly polarized VHF Yagi-Uda antenna to a circularly polarized antenna. This new kind of antenna is known as Offset Yagi-Uda Antenna.

In the traditional structure, the exciting element is normally a center-fed dipole placed on the bisector of the corner angle, parallel to the apex of the reflector. This arrangement produces linearly polarized radiation. By properly choosing the distance between the dipole and the apex, and the angle of tilting, elliptically polarized radiation or even circularly polarized radiation can be obtained. This offers a simple way of making a circularly polarized antenna. As the wires' separation of the grid reflector is close together, the reflector can be considered as a smooth reflecting surface. As a rule of thumb, a separation of $\lambda/10$ is the upper limit.

Besides giving an analysis on the characteristics of the said Yagi-Uda Antenna, the influence of replacing the grid corner reflector by a smooth corner reflecting surface will be investigated. This will be done by considering the special case where the directors are excluded. Integro-differential equations are developed to obtain the current distribution as well as the input impedance of the antennas. For the analysis of the antenna with a smooth corner reflector, Image Theory is applied. Thus the corner angle is restricted only to $\beta = 180^\circ/N$, where N is any positive integer. The integro-differential equations are then solved by the Moment Method.

Tuesday AM

URSI-B Session 34

Ray and Asymptotic Methods - I

Chairs: R. J. Marhefka, The Ohio State University; R. G. Olsen, Washington State University

Room: W-108 *Time*: 8:15-12:00

A PTD CORNER DIFFRACTION COEFFICIENT THAT TAKES INTO ACCOUNT THE CURRENTS EMANATING FROM THE CORNER

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The currents on perfectly conducting square plates with side lengths up to seven wavelengths are calculated by the moment method for plane wave incidence. These currents are plotted in three-dimensional plots and it is thereby seen that the currents at the edges are large and that the currents at the corners are of the same magnitude as the ones along the edges. An approximate current is found by adding the physical optics current and the current obtained by the fringe wave currents from the four half planes with edges parallel to the edges of the plate. It is taken into account that fringe wave currents on half planes propagate in the direction given by the intersection of the Keller cones and the plate. By subtracting this approximate current from the moment method current we obtain a current which represents corner diffraction and higher order edge diffraction. This current is very small except along the edges of the plate. In some parts of the edges this large current can be explained by second order edge diffraction and in some parts it cannot. It is found that the currents due to the corners are not restricted to regions near the corners but that it looks as if currents launched at corners propagate along the edges. Because of secondary edge diffraction in some pats of the edges and the interaction between currents launched at different corners, it is not immediately possible to verify this. To overcome these problems losses are introduced in the surrounding media by letting the propagation constant be complex in the moment method program. By subtracting the approximate current from the new moment method current, it is seen that exponentially decaying currents are emanating from the corners and that their phase variation is that of a plane wave launched at the corner in question. From these numerical results obtained with losses present we can find the amplitude and phase of the currents launched at the corners in free space. By calculating amplitude and phase for different angles of incidence it is possible to construct explicit expressions for the field radiated by a corner.

A UNIFORM RAY APPROXIMATION OF THE SCATTERING BY POLYHEDRAL STRUCTURES USING WEDGE CURRENTS

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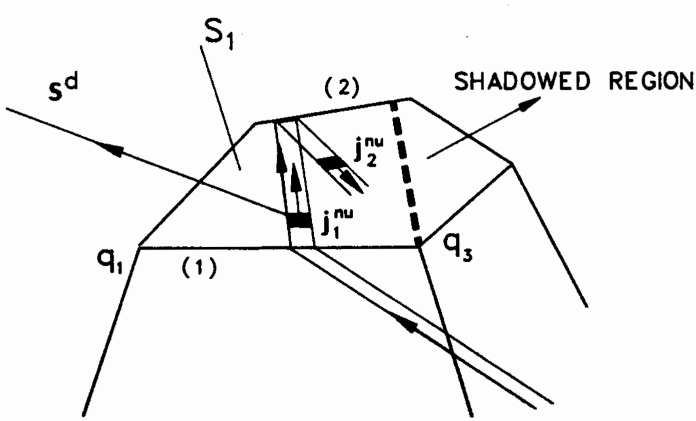
The three dimensional far field scattered by flat plate structures is investigated by (i) postulating an approximation of the induced surface current on each face of the object, and (ii) integrating the approximate current, either in closed form, or asymptotically in terms of the well tabulated edge transition function.

Specifically, the surface current on each plate composing the structure is approximated, in addition to the usual Physical Optics surface current, by a non-uniform current, which is derived from the canonical solution (integral representation) to the wedge problem, and truncated by the edges of the plate. The approximation is, in some respects, similar with Michaeli's secondary equivalent current development [Michaeli, AP-34, 1986]. Here, an attempt is made to present the total solution in terms of ray contributions, corresponding to tip, tip-to-edge and edge-to-tip diffracted rays. These rays result from the asymptotic surface current integration and do not satisfy, in general, Fermat's principle. Nevertheless, the final solution is as efficient as GTD in high frequency calculations and yields accurate results in many situations.

The superposition of a secondary non-uniform current, which can be asymptotically represented by a Michaeli's fringe equivalent source, excited by doubly diffracted rays is also studied. This secondary fringe current can be integrated in closed form in the far field resulting to similar ray contributions, which serve as an additive correction to the primary non-uniform current truncation effect and the corner diffraction solution [Brinkley and Marhefka, ACES Jour., Vol. 3, No. 2, 1988].



DIFFRACTION BY A METALLIC WEDGE WITH ROUNDED EDGE

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CESTA - BP n° 2
33114 - LE BARP FRANCE

The diffraction by a metallic wedge with rounded edge is studied parametrically for different values of KR, where K and R are respectively the wave number and the radius of the cylindrical cap on the edge. Following Ross and Hamid (IEEE AP 71) a separation of variable technique is used for KR in the range 0 to 5.

For KR small, the general diffraction coefficient merges asymptotically with the diffraction coefficient for a sharp wedge.

For KR moderatly large, the general diffraction coefficient converge towards the diffraction coefficient by a curvatuve discontinuity. However, due to poor matrix conditioning for the general solution when KR is large, instabilities generate some spurious oscillations.

An engineering approximation is simply derived by means of linear interpolation between the two asymptotic solution. The precision is within 2 dB on the diffraction coefficient.

Evaluation of the Dispersion Characteristics, Polarization and Excitation Strengths of Source-Excited Vector Fields on a Dielectric-Clad Circular Cylinder

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Thin dielectric layers on perfectly conducting substrates play an important role in applications involving printed circuits and radiating elements. When the substrate is of nonplanar shape (for example, the wing of an airplane), the determination of the electromagnetic wave properties in such an environment requires an understanding of the effects of layer curvature. Study of the circular cylindrical prototype represents a first step in this direction provided that its canonical behavior is parametrized in a manner suitable for subsequent generalization to noncircular geometries. The starting point for the vector-dipole-excited fields (dyadic Green's functions) on a layer-clad circular cylinder is a double integral representation over the complex wavenumbers ν and β which arise from spectral decomposition of the full Green's function with respect to the axial (z) and the infinitely extended azimuthal (ϕ) coordinate, respectively; the (ϕ,z) domain conforms to the layer geometry. To chart the propagation characteristics of the dipole excited layer-guided modes, it is necessary to solve the radial eigenvalue problem for the complex azimuthal modal propagation coefficients $\nu_p(\beta)$, p=1,2..., which also identify pole locations in the (ν,β) spectral integrand. With "b" representing the layer reference radius, the resulting [Re(ν_p/b),β] dispersion surface, which is generally anisotropic, determines the modal behavior along the various helical paths emanating from the source in the (ϕ,z) domain; the modal amplitudes result from residue evaluation at these poles in the complex ν-plane.

For the preliminary results reported previously [L.B. Felsen, I.T. Lu and K. Naishadham, Proc. URSI EM Theory Symposium, Stockholm, Sweden, Aug. 1989], the numerical determination of the $\nu_p(\beta)$ poles was based on a computation intensive contour integration technique involving Bessel functions with complex order and argument. An alternative and more efficient procedure, based on Davidenko's method [S.H. Talisa, IEEE Trans. MTT-33, 967-971, 1985], has been developed since then and will be described in detail. This improved method is now being applied to the generation of the [Re(ν_p/b),β] dispersion surfaces for various thin layer parameters (radius, thickness, dielectric constant) to assess their influence on the layer-guided propagation. These results will then be used to calculate the source-free fields along circles located at various distances from the source; this reveals polarization of the field as a function of observation angle (pitch of the helical propagation paths). Weighting of these fields by the modal excitation amplitudes (residues at the $\nu_p(\beta)$ poles) yields the complete integrand in the β-integral that must be evaluated to generate the reference solution, with which subsequent asymptotic reductions are to be compared. The results obtained, and their implications, will be discussed in detail.

DIFFRACTION BY A SMOOTH COATED CYLINDER SIMULATED WITH GENERALIZED IMPEDANCE BOUNDARY CONDITIONS

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Abstract

A rigorous UTD (Uniform Geometrical Theory of Diffraction) analysis of the diffraction by a coated circular cylinder simulated with generalized impedance boundary conditions is presented. The analysis parallels the one employed for the perfectly conducting cylinder (P.H. Pathak, Radio Sci. 14, 419-435, 1979). Ray solutions are obtained which remain valid in the transition region and uniformly reduce to those in the lit and the shadow regions. In addition, a ray solution is presented when the observation point is in the close vicinity of the cylinder. The resulting transition region expressions are in terms of functions which replace the Fock-type integrals, characteristic to the impedance cylinder diffraction coefficients. Their evaluation is performed numerically in a manner which parallels that employed for the usual Fock-type integrals. Diffraction coefficients applicable to convex cylinders are obtained in the usual heuristic manner.

CREEPING RAY CONTRIBUTION TO OFF AXIS BACKSCATTERING FROM A CONE WITH ROUNDED EDGE

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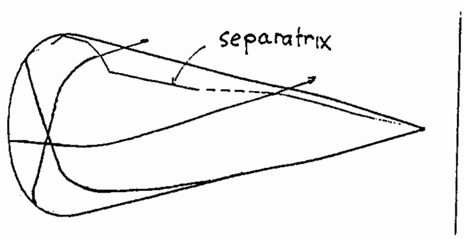
33114 - LE BARP FRANCE

The creeping ray contribution to backscattering from a conducting general cone-like shape with rounded edge is computed using GTD. The shape is described in CAD format using local polynonial maps. The light shadow separatrix and the geodesic lines are computed numerically. A Runge Kutta algorithm is used for the geodesic lines. The rays contributing to backscattering are determined : 3 rays are found for the general case, just as for the cone sphere (ref Choi and al APS-URSI SAN JOSE 1989) or for the flat base cone (ref Peters URSI STOCKHOLM 1989), as illustrated in the figure, for an incidence of 20°. The RCS is computed for the 2 canonical polarisations.



The results are compared, for several incidences and a wide range of frequencies with a Galerkin method of moment solution. The creeping rays contribution in this solution is isolated using impulse response filtering. The agreement between the two solutions is within 2 dB at high frequency.

New Hybrid Ray-Mode Algorithm for Repairing Ray Field Failures Associated With Trapped-to-Leaky Transitions in an Inhomogeneous Open Waveguide

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Leaky ducts with inhomogeneous cross section profile serve as models for electromagnetic wave propagation channels in environments as diverse as optical graded index waveguides and tropospheric layers near the earth's surface. At high frequencies, it is inefficient to calculate a ducted source excited signal by mode summation because of the large number of trapped propagating modes. In fact, in certain observation regions, reference solutions generated by trapped and leaky mode superposition reveal features that can be reproduced more efficiently, and with better adherence to the physical wave phenomena, by ray field tracing. This suggests use of a self-consistent hybrid ray-mode format that was developed previously by the authors. In the hybrid description, strongly refracted wave forms which follow highly oscillatory trajectories are accounted for collectively by a few trapped modes whereas wave groups which follow more weakly refracted trajectories with few oscillations are described by conventional ray fields augmented by uniform corrections near caustics. We have shown previously that this hybrid combination, which parametrizes the observed signal in terms of the simplest relevant wave phenomena, is numerically accurate when source and observer are located well inside the duct. However, the ray fields fail in the transition region surrounding the critical trajectory that grazes the duct boundary (refractive index minimum) beyond which leakage occurs; the grazing ray splits into a part that returns to the duct and a part that escapes from the duct. The approach to grazing and the ray splitting beyond, which manifests itself as two separately observed "beams", can be accounted for uniformly by a group of trapped and leaky modes whose local plane wave congruences are closely aligned with the critical (grazing) trajectory. Thus, by incorporating this mode group self-consistently into the previous format, the new hybrid ray-mode algorithm accommodates sources and observers located arbitrarily inside the duct, outside the duct, or on the duct boundary. This is illustrated by calculations for a line-source-excited surface duct with a bilinear refractive index profile extending away from a perfectly conducting boundary. The validity of the new hybrid form is confirmed by comparison with a reference solution generated entirely by mode summation.

APPLICATION OF WATSON'S TRANSFORM TO SCATTERING FROM AN ANISOTROPICALLY COATED CYLINDER

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Recently, the exact series solution for scattering of a plane wave by a perfectly conducting cylinder coated with an anisotropic material has been published (H. Massoudi, N.J. Damaskos and P.L.E. Uslenghi, "Scattering by a Composite and Anisotropic Circular Cylinder Structure: Exact Solution", Electromagnetics, Vol. 8, pp. 71-83, 1988). One of the interesting results is the appearance of complex order Bessel and Hankel functions in the series solution. We have reformulated Massoudi et al.'s results and presented them in a more conventional form. However, as with other series solutions for cylinders, this solution does not converge rapidly for electrically large cylinders. To remedy this, we have transformed the solution via the Watson transformation to a series which converges rapidly at high frequencies.

The transformed result is first presented in terms of a single geometric optics term and a series of creeping waves. Then the single geometric optics term is replaced by a series of geometric optics terms. Each term in this series corresponds to a ray which is reflected some number of times within the coating. Cases for which the relative permittivity and permeability are both greater than one and less than one are considered. The creeping wave terms is similarly expanded to become a series of additional geometric optics terms and two sets of creeping waves. One set of creeping waves is associated with the coating-air interface and the second is associated with the conducting cylinder-coating interface. Computer programs are used to implement the complex order Hankel functions and to study the complex pole locations. Bistatic scattered fields for both the E- and H-polarizations are also calculated and compared to the series solution.

UTD ANALYSIS OF AN ANTENNA CONVERTING WHISPERING GALLERY MODE PROPAGATING ALONG LARGE CIRCULAR WAVEGUIDE INTO LINEARLY POLARIZED BEAM

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High-power millimeter wave antennas, which convert a guided mode generated by a gyrotron and propagating along a large circular waveguide into linearly polarized beam, are used for the electron cyclotron resonance heating (ECH) of the fusion plasma. Because of the recent requirements of the higher power and the higher frequency in the ECH experiments, gyrotrons generating a whispering gallery (WG) mode have been developed. It is thus becoming very important to design an antenna converting the WG mode into linearly polarized beam.

The geometry of the reflector antenna converting the WG mode into the linearly polarized beam is shown in Fig.1, where the aperture of the circular waveguide is formed by a rotating cut and a straight cut. A design procedure of such antenna has been reported (O.Wada et al., Int. J. Electronics, 65, 3, 725-732, 1988). However, the geometrical optics (GO) have been used to obtain the field distribution on the reflector surface and the diffracted field by the edge of the aperture has been ignored. In this report, the results of UTD analysis of the mode converting antenna are presented. The field diffracted by the straight edge of the aperture is obtained by the UTD and the surface magnetic field on the reflector is shown in Fig.2. The radiation pattern is also calculated by using the physical optics indicating the significance of the edge-diffracted field.

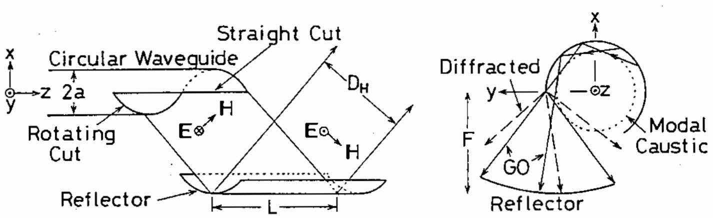

Fig.1 Geometry of reflector antenna converting WG mode into linearly polarized beam.

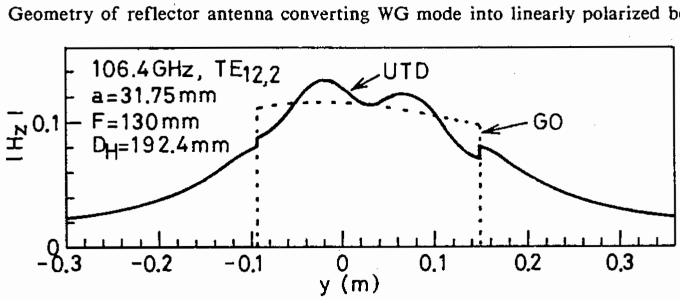

Fig.2 Magnetic field distribution on reflector surface.

THE FINITE ELLIPTIC CYLINDER AS A CALIBRATION TARGET

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The backscattered field from a solid metallic cylinder of elliptical cross section is studied. Such a scattering object may be useful as a calibration target in anechoic chambers.

Two complementary approaches are adopted. If the charasteristic dimensions of the target are not too large with respect to the wavelength, the surface current density is determined numerically as the solution of Maue's integral equation by combining the method of moments with isoparametric elements (R.D. Graglia, P.L.E. Uslenghi and R.S. Zich, Proc. IEEE, 77, 750-760, May 1989). The far field is subsequently obtained by integration over the surface current.

At very high frequencies, the backscattered field is determined directly by using the geometrical theory of diffraction. Both edge scattering and creeping waves are considered. Use is made of analytical tools previously developed in studying scattering by an elliptic metal plate (S.W. Lee and P.L.E. Uslenghi, J. Math. Phys., 15, 631-639, May 1974), by a finite cone (T.B.A. Senior and P.L.E. Uslenghi, Radio Science, 6, 393-406, March 1971; ibid., 8, 247-249, March 1973), and by curved surfaces. Formulas are developed for matching to axial and broadside results.

A comparison is made between numerical and asymptotic approaches, to verify that the results obtained vary smoothly as the frequency increases. Also, the above results are compared to measured data on an aluminum cylinder in anechoic chamber.

Tuesday AM1

URSI-B Session 35

Time Domain Numerical Techniques

Chairs: J. Chilo, LEMO; David C. Chang, University of Colorado at Boulder

Room: W-115 *Time*: 8:15-10:00

RESPONSE OF ELECTROMAGNETIC-PULSE LOGGING SONDE IN AXIALLY-SYMMETRICAL FORMATION

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The time-domain response of an electromagnetic-pulse logging sonde in axially-symmetrical formation is obtained using the transmission-line-matrix (TLM) technique. The sonde consists of transmitting and receiving coils that are placed on the axis of the borehole. The earth formation is assumed to have horizontal layers with or without invasion zones. The transmitting coil emits an electromagnetic pulse of known shape. Using the TLM technique, the transient response of the receiver may be computed. The technique calls for dividing the formation into small cells. Each cell is simulated with a matrix of transmission lines which are connected to those of the adjacent cells. The voltage and current in the transmission line network are proportional to the electric and the magnetic fields. The parameters of the transmission lines are so adjusted that the resulting transmission line equations correspond exactly to the Maxwell equations in the cell. Propagation of an electromagnetic pulse in the formation is then equivalent to the propagation of a pulse in the transmission line network. The latter may be obtained in a simple and systematic way with accurate results. Examples are given to show that the TLM technique is well-suited to solving time-domain well-logging problems in complex environments.

FREQUENCY DOMAIN ANALYSIS OF MICROSTRIP ANTENNAS USING TLM AND A PARAMETRIC METHOD

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The transmission line matrix (TLM) method enables simulation of interior electromagnetic field propagation problems by propagating pulses through a three-dimensional mesh. It yields the time domain response at each point of the bounded space investigated. In order to handle exterior problems such as radiation of a microstrip antenna, absorbent walls are introduced. However, since the CPU time and memory space involved are virtually prohibitive, the present paper focuses on a Prony-Pisarenko method to improve on the TLM method, in terms of both computation time and the precision of the frequency domain analysis of the results.

The Prony-Pisarenko Method : This method models the signal y(t) obtained using the TLM as a sum of p complex exponentials representing damped sine waves corresponding to the different modes for which we compute frequency f_k, damping α_k, amplitude A_k and phase Φ_k. Signal y(t) is composed of the deterministic signal s(t) and background noise b(t) :

$$s(t)= \sum_{k=1}^{p} A_k \exp(j\Phi_k) \exp(\alpha_k t+j2\pi f_k t) \qquad y(t)=s(t)+b(t)$$

The z-transform polynomial for s(t) is the following:

$$S(z)=\frac{B(z)}{A(z)}=\frac{b_0+b_1 z^{-1}+.....+b_{p-1} z^{-p+1}}{1+a_1 z^{-1}+......+a_p z^{-p}}$$

The coefficients of the polynomial A(z), which characterize α_k and f_k, are computed by minimizing noisy data, i.e, by determining the eigenvector corresponding to the minimum eigenvalue of the covariance matrix $[r_{kl}]$ of signal y(t). The coefficients of B(z), which characterize A_k and Φ_k, are computed *a posteriori* as the optimal initial conditions such that the deterministic signal s(t) is as close as possible to the signal y(t). This calls for use of the least squares method and application of the theorem of residues.

Application-characterisation of microstrip antennas : For the application in question, this method was compared with the Fast Fourier Transform, used in conjunction with the TLM method. For identical results, the present technique required three times fewer TLM iterations. In addition, since less memory space is needed, the method enables a finer description of the antennas. Current efforts are geared toward achieving radiation patterns for slot-coupled multilayer microstrip antennas. Results for these structures have already been obtained using TLM and the conventional Fourier Transform.

THE INTERFACE OF A FINITE-DIFFERENCE TIME-DOMAIN ELECTROMAGNETICS CODE WITH A TRANSMISSION-LINE/CIRCUIT CODE

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The Finite-Difference Time-Domain (FDTD) technique has been used for many years to predict the electromagnetic-pulse (EMP) and electromagnetic-radiation (EMR) response of systems with low to moderate complexity. These predictions normally require several steps in order to propagate the energy to the internal components of the system. Rarely, or perhaps never, have these predictions included the calculation of the response of internal circuitry "in-line" with the calculation of the external response of the system. This paper describes a technique to combine an FDTD code with a transient circuit analysis code so that coupling to circuit elements and/or IC pins can be computed directly. All of the complexity of the circuit board and its associated circuitry is modeled by the circuit code, freeing the FDTD code from the difficult problem of resolving the circuitry within the mesh.

This technique has been implemented by combining the FDTD code THREDH with a modified version of the code LineCAP, which solves circuit-board crosstalk problems using transmission-line assumptions between circuits. The system that we examined consisted of two boxes with conducting walls connected by a single multi-conductor cable. One box contained a circuit board with several traces. The technique to analyze this geometry can be summarized briefly as follows. The LineCAP subroutine takes driving currents computed on FDTD thin-wire models of cable conductors and provides the proper loading for these conductors. LineCAP also provides the correct reflections to be injected back into the cable conductors and therefore coupled back into the field solution. The interface takes place "in-line," and therefore provides a self-consistent solution as far as the cable/circuit-board interface is concerned. Direct field interaction with the circuit board traces from field leakage into the box through cracks, etc., is ignored.

In order to implement the technique, convenient methods for loading thin wires within an FDTD code have been developed. These methods will be presented and their validation demonstrated. Validation of the FDTD/circuit-board interface will be demonstrated by comparisons with analytic solutions for two wires and comparisons with measurements on the geometry described above. The addition of this thin-wire/circuit-board interface greatly enhances the ability of an FDTD code to predict the coupling of energy to the interior of a system.

A TIME DOMAIN METHOD TO ANALYZE DISSIPATIVE TRANSMISSION LINES

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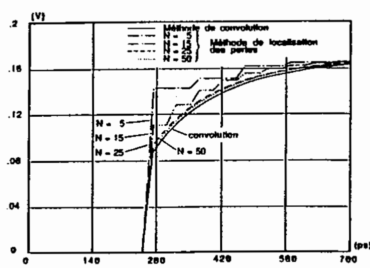
In high density printed circuits where narrow strips are used, or in silicium IC's where substrate conductivity is consiserable, power dissipation in transmission lines (spacially in high frequencies) is a factor to be introduced in any simulation calculus. To this time, plenty of methods are established to take into account losses in signal propagations. However for a time domain analysis of transmission lines only perturbational methods or analytical insolvable differential equations are available.

A convolution method which is introduced in this paper is not only a solution for lossy transmission problems but also a solution for any time domain analysis where nonlinear loads and dispersive distributed elements are present.

The principle of the method is based on the fact that a transmission line or a group of coupled transmission lines can be treated as linear passif quadripoles. One can define a transfer function in frequency domain and by inverse Fourier's transform determine this function in time domain. Then any nonlinear load or time defined signal sources convolve the transfer function to determine the output signals. A comparison is done (figure) between a perturbational mathod (distributed resistances along the line) and the convolution results. One note that the perturbational method gives acceptable results when line partition number is more than about 25. This uses a great amount of CPU time.



A TIME DOMAIN METHOD TO PREDICT CROSSTALKS AMONG LINES OF DIFFERENT LENGTH

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N. ELKAMOUN, J. CHILO
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In high density printed circuits or IC packages, crosstalks appear among strip-lines; this is the major density limiting factor. A time domain analysis is necessary (for digital circuits specially) to predict interference magnitudes in order to establish design rules. To this time, given methods consider circuit conductors (strip-lines) parallel and with the same length. It may be true in telecommunication lines or system connectors, but in printed circuits or IC packagings, majority of lines are not parallel neither of the same length. In this paper is presented a new time domain method which takes into account these phenomena.

The method is based on dividing a given interconnection structure into parallel and of the same length coupled lines (tubes); with this procedure the structure is transformed into a group of tubes joined together following any direction in the space. These tubes may have one, two, three or more coupled lines. The problem consists in analyzing signal propagation along the tubes and its distribution in the junctions. One can use well known numerical methods based on Schelkunoff's equations to analyze the signal propagation on the tubes; but for signal distribution in a junction, "Dilatation" and "Shrinkage" operators which are deduced from Kirchoff's laws may be used. These operators which adapte resistance and voltage matrices of tubes in a junction are explained in an IEEE short paper authored by T. Razban.

Some interesting results on printed circuits will illustrate the efficiency and usefullness of this method during the oral presentation.

Tuesday AM2

URSI-A Session 36

Device, Material, and Medium Measurements IIA

Chairs: Vasundara V. Varadan, The Pennnsylvania State University; Arlon T. Adams, Syracuse University

Room: W-115 *Time*: 10:15-12:00

MEASUREMENT OF THE CHIRALITY PARAMETER OF CHIRAL COMPOSITE MATERIALS IN THE 8 – 40 GHZ FREQUENCY RANGE

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Center for the Engineering of Electronic and Acoustic Materials
The Pennsylvania State University
University Park, PA 16802

Materials which lack inversion symmetry are characterized by the constitutive relations, $\mathbf{D} = \varepsilon\mathbf{E} + \beta\varepsilon\,\nabla \times \mathbf{E}$ and $\mathbf{B} = \mu\mathbf{H} + \beta\mu\,\nabla \times \mathbf{H}$. Such materials, called chiral or handed materials, exhibit a handedness in their microstructure. Several examples of naturally occurring chiral materials abound in nature, and such materials are optically active in the visible wavelengths. Although this phenomenon has been known and extensively studied for over a hundred years, optically active materials have never been completely characterized. Thus the material property β, unique to such materials, has never been measured before. Recently, there has been a renewed interest in this class of materials for applications in the microwave and millimeter wave frequencies. Chirality must be introduced artificially in such materials, resulting in chiral composite materials, which, just like optically active materials, have a different phase velocity and attenuation for left and right circularly polarized EM waves. The direct measurement of the complex material properties, ε,μ, and β for such materials prepared in our laboratory, with a free space set–up using planar samples, is presented for the 8 – 40 GHz frequency range. Two independent measurement methods, using normal and oblique illumination of the samples are used, and accurate calibration techniques have been developed for both methods. Results will be presented for left handed, right handed, and racemic or equichiral composite materials containing different volume fractions of chiral inclusions in the form of metal helices. It is concluded, that one can obtain much higher (up to three orders of magnitude) values of β for artificial chiral materials than in naturally occurring optically active materials. The implications of these properties for several applications will be discussed. More importantly, this is the first time such materials have been completely characterized using new measurement and calibration techniques for a wide range of frequencies.

FREE-SPACE MEASUREMENT OF DIELECTRIC CONSTANTS UNDER HIGH TEMPERATURE CONDITIONS AT MICROWAVE FREQUENCIES

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Free-space microwave measurements as described here are nondestructive and contactless, hence they are ideally suited for dielectric constant measurements of composite materials under high temperature conditions. A free-space measurement system operating in the 5.85 - 40 GHz frequency range was used to measure scattering coefficients S_{11} and S_{21} of planar samples. Dielectric constants of composite materials were calculated from the measured values of S_{11} and S_{21}. The key components of the free-space setup are a pair of spot focusing horn lens antennas, the network analyzer, mode transitions and a computer. Diffraction effects at the edges of the sample are minimized by using spot focusing horn lens antennas. Free-space TRL (through, reflect, line) calibration techniques along with time domain gating was used to eliminate errors due to multiple reflections between antennas via the surface of the sample. A planar sample of cross section 15.2 x 15.2 cm was placed in a furnace which operates in the temperature range of 25 - 800°C. This furnace is heated by electric heating units located around the top, bottom and side walls of the furnace. The front and back side of the furnace is enclosed by a material which is thermally insulating and transparent to microwave radiations. The furnace temperature is controlled by a SCR controller, a temperature controller and a thermocouple or black body sensor. The measurement system and calibration technique will be described. Experimental results will be presented in the frequency range of 8 - 18 GHz for several high temperature materials including boron nitride, silicon nitride and fused quartz.

COMPLEX PERMITTIVITY MEASUREMENT AT HIGH-FREQUENCY USING A MONOPOLE ANTENNA

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The objective of this research is to develop a simple probe to measure the complex permittivity of medium. Conventional methods usually involve sample holders, so the sample must be carefully prepared to conform to the exact dimensions of the sample holder. Improperly prepared samples are often a major source of measurement error. Also, for some samples it is very difficult to machine. A monopole antenna with a conducting plate used as a probe to measure the complex permittivity of medium has the advantage of not requiring a sample holder or needing a machined sample. In this method the antenna can be inserted directly into the medium to measure its complex permittivity.

The method is based on the idea that the input impedance of an antenna is a function of the complex permittivity of the medium. If this function is known, then either the impedance or the properties of the medium are known. A fractional polynomial expression is used to relate the input impedance of an antenna in a homogeneous medium to the complex permittivity of the medium. The least-square method is used to determine the constants in this polynomial through experimentation. A measurement system consisting of a monopole, a conducting plate, a network analyzer, and a computer and its peripherals is used in the experimental study of this technique. Saline solutions with concentration from 1 kppm to 10 kppm in the frequency range 700 MHz to 1200 MHz are used as test samples. For practical use, experiments for samples with finite sizes are also done to investigate the boundary effects. The minimum sizes of samples are determined experimentally and verified numerically.

STUDY OF A CONDUCTIVE POLYMER FOR APPLICATION AS A MICROWAVE ABSORBER AND AS AN EMI SHIELD

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Conductive polymers are lightweight dielectric materials whose conductivity can be increased by doping with p–type or n–type impurities. In this paper, we present data on the microwave conductivity of a heterocyclic polymer, poly–p–phenylene–benzobis–thiazole (PBT), and discuss possible application of this material as a microwave (radar) absorber and as an EMI shield.

The polymer PBT in its pristine form is a lossless dielectric with a dielectric constant of about 3. Data on the microwave conductivity of an iodine–doped thin–film PBT sample, measured at a frequency of 10 GHz using the cavity perturbation technique, has been reported in a recent publication (A.B. Bidarian and P.K. Kadaba, J. Mat. Sci. Lett. 7, 922–923, 1988). Ion–implantation technique has been used for doping the film to a fluence of 10^{15} ions/cm^2 at 335 keV. Because of the uniform penetration of the dopant into a surface layer of the film, the film can be modeled as a two–layer dielectric, with one dielectric corresponding to the doped layer accompanied by a high microwave conductivity, and the other, to the undoped intrinsic layer, characterized by no losses. We have calculated the electromagnetic interference (EMI) shielding effectiveness of this doped film from the measured data on the conductivity by computing the amplitude of the field transmitted through the film. The results indicate a low transmission coefficient (0.1 or less), pointing to the potential application of the doped film as a lightweight EMI shield. As a second implementation, we have considered the utilization of the doped PBT film in an electric Salisbury screen radar absorber, which consists of the doped film contiguous to a lossless dielectric layer (relative permittivity 9.9) on a perfectly conducting backing. Results concerning the influence of the physical parameters of the screen (e.g., thickness, material loss, etc.) in achieving a low reflection coefficient will be discussed.

ACCURATE MEASUREMENT OF COMPLEX PERMITTIVITY AND PERMEABILITY BY NULL-BALANCE TECHNIQUES

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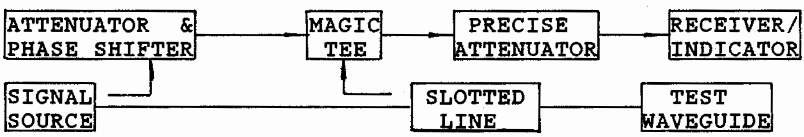
ABSTRACT- A new null-balance technique is developed to measure the complex permittivity of dielectrics accurately at X-band. The measuring system mainly consists of a microwave bridge, a slotted line and a sensitive receiving system (shown below). For the sake of obtaining satisfactory data, the attenuation and phase information are measured in seperated branches.



The former is derived from the output of the Magic Tee via a precise polarizing attenuator,the latter is taken close to the specimen by a slotted line. The procedure of null-balance technique can be summarized as follows. First, short-circuit the hollow waveguide, adjust the changable attenuator and the phase shifter, make the bridge balanced, the signal accepted by receiver will tend to zero. It is a vectorial sum of reflected signal from the short (denoted by -1) and that from the adjustable branch and those leaked in due to imperfect isolation of the two directional couplers (denoted by +1). Then replace the short by a section of short-circuited waveguide of about one quarter wave-length, the synthetic signal will indicate the realistic level of -1 and +1 via a simple geometric relation. After that, insert specimen into the waveguide and measure the amplitude of the synthetic signal and the phase of the reflection from the specimen, we can obtain the permittivity by calculation. Care must be taken that in general there may be present two different solutions, and we should select a correct one. In order to cut down the influence of unwanted reflections on precision, in addition to inserting necessary isolation, an optimum length of specimen is suggested, which is of greate significance especially for low-loss material. It is so selected that the reflection phase can keep fixed before and after inserting the specimen in. The method presented above has been proved effective and expanded to measurement of permeability successfully.

Tuesday AM

URSI-B Session 37

EM Coupling and Shielding

Chairs: Chalmers M. Butler, Clemson University; J. Dunn, University of Colorado at Boulder

Room: W-104 *Time*: 8:15-12:00

CONTRIBUTIONS TO THE COMPUTATION OF THE MUTUAL COUPLING BETWEEN EDGE SLOTS IN RECTANGULAR WAVEGUIDE

J.P.Jacobs* and D.A.McNamara
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The numerical determination of the mutual coupling properties between inclined slots in the narrow wall of rectangular waveguide (edge slots) has not enjoyed much attention in the literature. In fact no information appears to be available in the literature, either on how to compute such properties or in the form of measured data presented in the form of curves, that can be used for design purposes. The authors are currently undertaking a study in an attempt to remove this deficiency.

Computation of the mutual coupling between two slots requires that the electric field distribution in the egde slot be known with some accuracy. This does not appear to have thus far been ascertained with any certainty. In this paper we apply a method of moments triangular surface patch technique to model a section of waveguide in which there is an edge slot, and compute the slot field distribution. Although this is computationally intensive, it should be remembered that its use is not intended as part of a design procedure but purely to obtain reliable information on how to accurately approximate the slot field distribution.

In the next step these known slot distributions can be used with a second moment method formulation, by which the mutual coupling between two impressed magnetic currents (the now known slot field distributions) on an infinitely long conducting cylinder (in this case the rectangular waveguide exterior) can be determined. Computational efficiency is provided by use of a transform approach, with a moment method solution of the combined field integral equation being utilised to remove the possibility of internal resonance problems.

In the presentation the results which have thus far been obtained using the above approaches will be described and evaluated.

MUTUAL COUPLING IN PHASED ARRAYS SCANNED TO ENDFIRE

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Planar phased arrays are not usually scanned to low elevation angles because of difficulty in matching the input impedance of the antenna elements over a wide range of scan angles. In certain applications it is desired to scan only at low elevation angles and matching near broadside is not required. Impedance matching is still a problem in this case, since mutual coupling between elements is greater than in arrays designed for near broadside operation. This is because the elements must have gain at low angles, which implies that elements are coupled via their main lobes. To form a beam on the horizon a wave must build up as it propagates across the face of the array. Consequently, elements near the leading edge of the array tend to be illuminated much more strongly than elements at other locations. This results in wide variations in input impedance as the array is scanned in azimuth.

In analyzing finite arrays it is often assumed that an element's input impedance is not significantly different from that of an element in an infinite array where Floquet's theorem can be applied. This assumption is not valid in the case of low elevation scan angles for the reasons discussed above. A computer program has been developed which estimates the active impedance of elements in a finite array. For each element the program sums the coupled fields from every other element in the array. The direct and first order scattered contributions are taken into account with the assumption that the face of the array is effectively a lossy surface due to absorption of energy by intervening elements along the coupling ray paths. Results of analysis of endfire conformal arrays of various configurations will be presented.

COUPLING BETWEEN A CYLINDRICAL SCATTERER AND A SLOTTED PARALLEL-PLATE WAVEGUIDE

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Electromagnetic field penetration through a slot in a parallel-plate waveguide with coupling to an exterior conducting cylinder is considered in this paper. The axes of the cylinder and slot are parallel, and excitation results from a TEM field in the guide incident upon the slot and a source in the region exterior to the guide. Excitation is limited to sources which cause the field components to be invariant with respect to displacement along the slot and cylinder axes. Interest lies in two major effects. First, there is interest in the loading of the guide and modification of the slotted-guide radiation pattern due to the presence of the cylinder. Second, we are interested in the effectiveness of a conducting shield placed near/over the slot to reduce penetration from an external source into the guide. Two cases are treated. In one the slot is in a wall of an otherwise continuous guide and in the other the guide terminates in a conducting screen with the structure opening into a half- space. Coupled integral equations are formulated for the slot electric field and the cylinder surface current, and these equations are solved numerically. Because the slot is in a waveguide, a kernel of the integral equations possesses a term which is an infinite series. In the two cases under consideration, the series are different and have different convergence rates. Special care is given to acceleration of these series to arrive at a numerically efficient solution procedure. Integral equation solutions are obtained in the two cases for several sets of cylinder-slot parameters. Slot electric field and cylinder current are presented as are radiation pattern, reflection coefficient, and penetrated field. Sufficient data are given to allow one to assess the effects of the slot-cylinder coupling in shielding and radiation problems.

MODELING OF PARASITIC COUPLING IN MICROSTRIP CIRCUITS USING A PERTURBATION TECHNIQUE

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On a local microstrip network, the parasitic coupling of adjacent microstrip lines may often produce undesirable effects on S-Parameter measurements. This effect increases as the parasitic line approaches the microstrip line of interest. This is exemplified by the undesirable effects induced at either the input of an active device (such as a high gain amplifier) or on a highly resonant circuit (such as a filter).

The purpose of this work is to derive a general approach toward dealing with parasitic effects on MMIC circuits when the parasitic problem involves "loose" coupling. The approach is to first solve for the network's S-Parameter values disregarding all parasitic effects. This is accomplished using currently available software packages. The unperturbed S-Parameters are then used to solve for voltages and currents everywhere in the local network. Through analysis of the induced vector magnetic potential, dependent voltage sources are developed which ultimately are reincorporated into the original network for reanalysis by the commercial software package. The resulting S-Parameters give first order perturbed results demonstrating the effect of the parasitic line. The geometry of this method is simple to construct, and it is anticipated this approach will be more computationally efficient that full wave integral equation methods. The method also takes advantage of utilizing commercially available software packages.

This talk will discuss advances made in the method since the last URSI meeting in Boulder, Colorado, January of 1990. In particular, the dielectric substrate is fully accounted for, and ways of significantly speeding up the calculation have been studied. We also have investigated a number of more complicated geometries beside the simple resonator near a line, which was discussedd in January's meeting. These more complicated structures, for example a double-tee tuner, have also been examined experimentally. Comparison between theory and experiment will be made.

CALCULATIONS OF THE COUPLING BETWEEN TWO LINE SOURCES IN THE PRESENCE OF AN IMPEDANCE WEDGE

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R. Tiberio, G. Pelosi
Dept. Ingegneria Elettronica, University of Florence

P.H. Pathak
Dept. of Electrical Engineering, The Ohio State University

A Uniform GTD (UTD) solution has been recently presented for the diffraction by a wedge with surface impedance faces, when both the source and the observation points are located at finite distances from its edge [R.Tiberio et al., IEEE Trans. Antennas Propagat., vol. AP-37, no. 2, Feb. 1989]. There surface wave contributions are not yet treated explicitly. This solution was extended to treat the case when either or both the source and the observation point are on the face of the wedge [G.Manara et al., IEEE AP-S/URSI Symp., 1989].

In this paper the solution is completed by including surface wave contributions. To this end, the Geometrical Optics field is generalized to account for the surface wave that may be directly excited by the source on either face of the wedge. Thus, a more complex field impinges on the edge and excites several scattering mechanisms. The present formulation is uniform at the shadow boundaries of surface waves and nicely describes the coupling between surface and space waves which may be established, whenever an edge in an impedance wedge is illuminated by a spectrum of plane waves. It is shown that this solution may provide a useful tool in designing surface wave antennas.

Numerical results are presented to analyze the surface wave excitation conditions and to discuss the importance of the various contributions.

ANALYSIS OF SHIELDED SLOT-COUPLED DIRECTIONAL COUPLERS BETWEEN DOUBLE-SIDED SUBSTRATE MICROSTRIP LINES

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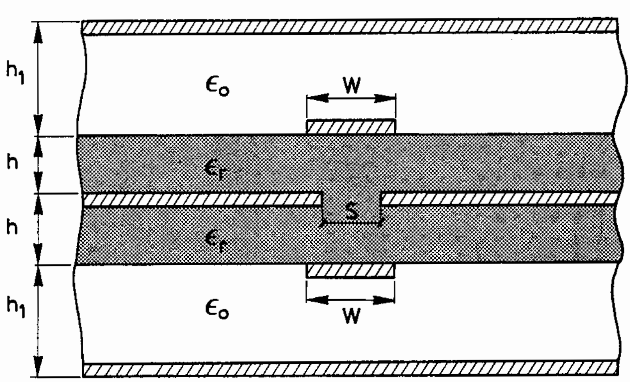
This paper proposes to study the characteristics of a newly slot-coupled directional coupler between two microstrip lines coupled through a rectangular slot in the common ground plane (Fig.1). The etching of this slot modifies mainly the even mode characteristic impedance and phase velocity in such a manner to alter the directivity and to allow to achieve both tight and loose coupling values.

Hence, in this paper, quasi static analysis of shielded slot-coupled directional couplers between double-sided substrate microstrip lines is performed using conformal transformation techniques for calculating their even and odd-mode capacitances per unit length. This analysis leads to rigourous analytic closed form expressions for their even and odd-impedances and their even and odd-mode propagation constants for any lines configurations and substrate thikness. Design curves giving odd and even-mode characteristics in terms of dimensions of this slot-coupled directional coupler cross section are presented. Results for the limiting case of $h_1 >> h$ which is that of unshielded slot-coupled directional couplers are also given.



BELOW APERTURE CUTOFF FREQUENCY SHIELDING PRIMARY DEPENDENCE ON APERTURE TRANSMISSIVITY AND OHMIC LOSSES

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A cylindrical shield breached by a rectangular aperture has been an object of study both numerically using the Finite Difference Time Domain (FDTD) technique and experimentally using the EMPEROR facility at the Lawrence Livermore National Laboratory. Reasonable shielding characterization of the response of an interior wire was achieved at frequencies above the aperture cutoff. Below aperture cutoff the response was not as well characterized in that the interior resonances on the wire were extremely sharp and not well resolved, the result of the very low transmissivity of EM energy across the aperture below aperture cutoff.

Further numerical studies of a similar rectangular cavity/wire system were performed at Penn State with up to one million time steps to adequately resolve the response. Without ohmic losses the interior wire response below cutoff was characterized by sharper resonances with smaller apertures. For smaller apertures the resonances below aperture cutoff grew in amplitude so that the energy in each resonance over a fairly wide range of aperture sizes remained roughly constant. Only by allowing for ohmic losses is there any reduction in the energy of the resonances and hence any effective shielding from an energy on the wire viewpoint.

We conclude that below aperture cutoff frequency shielding for this type of geometry depends on characteristic times, namely the time rate of energy flow across the aperture versus time rate of ohmic energy loss.

NUMERICAL COMPUTATION OF THE EM COUPLING BETWEEN PORTABLE RADIO DIPOLE-ANTENNA AND HUMAN BODY MODEL BY COUPLED INTEGRAL EQUATIONS AND 3-D MOMENT METHOD

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Recently the rapid progress of portable/mobile communication technologies has rendered portable/mobile radios (or phones) with more compact size and higher transmitting power. Since the human operator of portable transmitters is in very near proximity to the radiating antenna, possible biological hazard due to the electromagnetic energy coupling from the antenna to the human body (especially the head) has become a public concern. Moreover, the coupling effect between the antenna and the body which will significantly change the antenna impedance and radiating patterns has to be considered for design specifications of the radio and antenna performance-characteristics.

In this paper, a supercomputer simulation process is presented to numerically compute the EM coupling between a realistic human model and a radiating dipole-antenna at proximity. Coupled integral equations (CIE), Hallen's Integral Equation (HIE) for the dipole antenna and Electric Field Integral Equation (EFIE) for the human body model, are employed to formulate this EM coupling problem. Moment Methods with pulse-basis functions (1-D for the dipole antenna and 3-D for the body model) are used to solve the unknown induced field (or current) numerically. A human model with a realistic shape was constructed and partitioned into about 1400 nonuniform cubic cells (about 300 cells modelling the head) for numerical computation. This modelling generates a huge complex/dense matrix equation with the order of about (4250 x 4250). The matrix order is equal to (NA + 3NB) of which NA is the number of 1-D segment modelling for the antenna and NB is the number of 3-D cubic-cell modelling for the body model. Symmetry can be applied to reduce the matrix-equation order to one half (about 2150 x 2150). However even with symmetry, it still needs about 10 Megawords computer core-memory to solve this complex and dense matrix equation by the Guassian Elimination Method (GEM). CRAY-2 supercomputer (128 Megawords core memory) is hence the best supercomputing platform for this huge computational problem (CRAY-XMP/48 has only 8 Megawords core memory which is not enough for solving this problem unless the 128 Megawords Second Semiconductor Memory (SSD) in CRAY-XMP can be accessed).

Numerical results and comparison with experimental measuring of induced SAR (Specific Absorption Rate) inside the head of a phantom model and antenna patterns will be presented in the meeting. CPU time cost to solve this problem in CRAY-2 supercomputer and possible vectorization speedup will also be discussed.

EXPERIMENTAL STUDY OF NARROW SLOT APERTURES HAVING DEPTH

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Electromagnetic penetration into shielded enclosures through narrow slot apertures is an important problem. Apertures can be created at any mechanical interface. An exmpale is the apparent aperture created by the bowing of two metal sheets that have been riveted together. Penetration into the enclosure by high power microwaves can cause unwanted system upset or burnout. Warne and Chen (1989) derived simple antenna and transmission-line models for narrow slot apertures having depth which take into account skin effects. An experimental study was performed to validate the theoretical models.

In this work, experiments have been conducted in the 2-4 GHz range measuring the electromagnetic energy coupled by apertures having various widths and depths. Slot widths were varied from 0.002 to 0.125 inches. Their depths ranged from 0.125 to 0.50 inches. The apertures were two inches in length so that the first resonance of the slot was excited in the given frequency band. The slots were mounted onto a large ground plane attached to a shielded enclosure so that an aperture in an infinite ground plane was simulated. The fields coupled into the enclosure were sampled in the Fraunhofer region with small electric and magnetic probles mounted on the ground plane containing the aperture.

The results of the experiment are compared with the transmission-line and dipole models which account for material conductivity. Both the peak values at resonance as well as the measured quality factor are compared with the numerical results. Good agreement over the frequency band is shown between the experiments and numerical models for the configurations considered. Possible extensions to the ongoing experiments are considered such as slot loading by gaskets, simple cavities, and transmission lines.

ELECTROMAGNETIC SHIELDING: THEORY AND PRACTICE

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Anyone who is familiar with the vast body of literature dealing with shielding theory but has never applied this theory to an actual system, probably has a distorted view of the way electromagnetic shields work. This is because textbooks, journal articles, and sales literature generally describe the operation of shields in terms of reflection, re-reflection and absorption of an incident electromagnetic wave. A detailed analysis of a plane wave normally incident on an infinite slab of lossy dielectric material is often followed by less-detailed arguments that attempt to extend the plane-wave results to account for the near-field behavior of a shielding material. Sometimes, references to the reciprocity theorem are used to imply that the approach to shielding a radiation source is the same as the approach to shielding a radiation receptor.

Applying this theory, one might expect a simple copper shield to reduce the radiated emissions from a small circuit by 50 - 100 dB. In practice however, reductions of this magnitude are rarely realized. Conventional wisdom dictates that seams and apertures in the shield are the reason for this discrepancy. For this reason, shielding literature generally includes a discussion of radiation from slots and apertures.

This approach to shielding theory is relatively easy to grasp and provides some basic rules-of-thumb for shield designers. Unfortunately, it is not complete and it is of little value for accurately predicting the effectiveness of any particular design. Shields tend to be located either near the source or near the receptor of the radiation. As a result, they are most often an integral part of the system's *antenna*. For example, an electrically short wire driven by a voltage source may be a much more efficient radiator when it is "shielded" by a metal enclosure with a small opening. This is because the enclosure lowers the input impedance at the source. The amount of power reflected and absorbed by the enclosure is more than compensated for by the additional power delivered by the source.

Traditional shielding theory has very few practical applications. Designing an effective shield for a particular circuit is actually an antenna design problem where both the circuit and the shield are elements of the antenna. This presentation discusses numerical modeling techniques that can be helpful in this analysis and an approach for reducing complex circuit configurations to relatively simple antenna problems.

Tuesday AM
Joint AP-S, URSI-B Session 38
Polarimetric Measurements

Chairs: Andrew J. Blanchard, HARC/STAR; Y.M. M. Antar, Royal Military College

Room: W-110 *Time*: 8:15-12:00

8:20	**Calibration Targets for Polarimetric RCS Measurements** Y.M. M. Antar*, Royal Military College; S. R. Mishra, David Florida Laboratory; Ahmed A. Kishk, University of Mississippi	208
8:40	**The Polarization Purity of Dihedral and Trihedral Corner Reflectors** D. Kahny, University Karlsruhe; J. van Zyl, Jet Propulsion Laboratory; W. Wiesbeck*, University Karlsruhe	209
9:00	**FM-CW Radar Applied to the Detection of Buried Objects in Snowpack** Yoshio Yamaguchi*, Masakazu Sengoku, Takeo Abe, Niigata Unviersity; Wolfgang-M Boerner, The University of Illinois at Chicago	AP-S
9:20	**Polarization Diverse Microwave Imaging** Richard F. Schindel*, Andrew J. Blanchard, HARC/STAR	210
9:40	**Experimental Observation of the Polarization Dependence of Bistatic Scattering** K.V. N. Rao*, W. G. Stevens, J. Mendonca, J. C. DiLeo, Rome Air Development Center	211
10:00	**Coffee Break**	
10:20	**Millimeter-Wave Radiometric Imaging** H. Suess*, K. Gruener, German Aerospace Research Establishment	AP-S
10:40	**Active Sensing of Spatial Defects Using a Microwave Imager** A. Z. Tirkel*, C. F. Osborne, Chisholm Institute of Technology	AP-S
11:00	**A Bistatic Polarimetric Radar Cross-Section Measurement and Imaging Facility** J. W. Bredow*, E. C. Nance, A. K. Fung, University of Texas at Arlington	212
11:20	**Near Field Imaging for Conducting Objects** Hsueh-Jyh Li*, Feng-Li Lin, National Taiwan University	AP-S
11:40	**High Resolution Radar Imaging with Small Subarrays** Jenho Tsao*, National Taiwan University	AP-S

CALIBRATION TARGETS FOR

POLARIMETRIC RCS MEASUREMENTS

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University of Mississippi, University, MS

ABSTRACT

Polarimetric Radar Cross Section (RCS) measurements require determination of orthogonal components (co polar and cross polar) return and their relative phase relationship in order to completely characterize the scattering matrix. Measurements may be made using any polarization basis (eg linear or circular) and then one can use applicable transformation to calculate the scattering matrix for any other polarization basis required for a specific application (eg. optimal polarization). In practice accurate measurements depend on the appropriate choice of calibration targets.

This paper discusses characteristics of a variety of basic targets and their suitability for calibrating polarimetric radars and RCS measurement systems. Results of measurements using circular polarization, and linear polarization over a wide frequency range, are presented. Measured data is complemented with computed results obtained using reliable numerical techniques. Some considerations in selection of calibration targets for accurate RCS measurements are highlighted.

The Polarization Purity of Dihedral and Trihedral Corner Reflectors

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Corner Reflectors are still the most effective targets for radiometric SAR calibration. They are commonly regarded to have a high polarization purity. This paper will present the result of a joint IHE/JPL research work, where at the IHE high precision laboratory measurements and by JPL airborne SAR-measurements were performed. The goal of the research work is the verification of the theoretical results for corner reflectors (trihedrals) regarding especially the

- boresight and off-boresight cross-polarization purity,
- the ratio of $\underline{S}_{vv}$ to $\underline{S}_{hh}$ as a function of the aspect angle and frequency,
- the influence of the finite edge thickness on the scattering behavior.

Preliminary wide-band laboratory measurements showed, that the edges have a considerable influence on the measured scattering cross section of trihedral corner reflectors. We shall examine this effect in detail through both laboratory measurements and theoretical analysis. The theoretical results will be compared with the laboratory measurements as well as airborne SAR-measurements made during the summer of 1989. We anticipate that in spite of the problems outlined above, the errors will still be within the commonly accepted error range for air- and spaceborne SAR applications.

POLARIZATION DIVERSE MICROWAVE IMAGING

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Current microwave imaging technology is based on the scalar diffraction limited formulation known as the Porter-Bojarski equation. This formulation does not implicitly use polarization information. An equivalent vector formulation of the inverse scattering problem, which utilizes polarization information implicitly, is unsuccessful in that it recovers the gradient of the scattering sources. Without further point mathematics, an image of the electromagnetic sources supported by the target cannot be reconstructed. It is possible, however, to make use of polarization information explicitly with the scalar inversion algorithm.

The first attempted, and most basic use of polarization information directly adds intensity reconstructions of two different like-polarized images (N.H.Farhat, et al, Radio Science,Oct.,1984). Since no single polarized image is presented, it is not clear whether this method of combining polarization information actually enhances the image quality. More recently, this method, as well as another method, of utilizing polarization information has been investigated (R.F. Schindel, Ph.D. Dissertation, UT Arlington, Dec. 1989). This research has shown that combining polarization information by addition of intensity profiles serves to decrease the dynamic range required to reproduce the secondary source distribution comprising the image. Thus, this method of polarization enhancement may prove useful for increasing SNR. The second method of using polarization information relies on the fact that deterministic targets have deterministic spectra (M. Dolaty, Masters Thesis, UT Arlington, May 1989). In other words, deterministic targets support spectral sources which are localized within specific angular regions of the far-field spectrum. Furthermore, these localized angular regions remain constant regardless of transmit and receive polarization configurations. Therefore, the complete target can be formed by choosing the best polarization for each of these substructures of the target.

As an experimental example of angular discrimination of target substructures, the field scattered from a metallized model of a B1-B aircraft is measured for the four principle linear transmit/receive polarizations. It is shown that three substructures of the target are identifiable as distinct angular regions in the far-field spectra. These substructures include each wing, and the fuselage and tail section. In any given homogeneously polarized image, the tail section of the aircraft is obscured by mutual coupling of the target with the chamber and support structures, as well as by the different shadow functions produced by the calibration target and the model aircraft. By reconstructing the wings from the like polarized vertical-vertical polarization, and reconstructing the tail and fuselage from the horizontal-vertical polarization, the obscurations become less severe, and the image of the tail section is enhanced. This method may be generalizable to a point-by-point choice of polarization.

EXPERIMENTAL OBSERVATION OF THE POLARIZATION DEPENDENCE OF BISTATIC SCATTERING

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The bistatic reflected clutter power from deciduous trees (mixture of Birch, Maple, and Ash) at 3.2 GHz has been measured as a function of the receiver polarization angle. Data was obtained for two configurations: incidence angle of 76 degrees, elevation scattering angle of 85 degrees, and two azimuthal angles of 15 degrees and 40 degrees from the forward scattering direction. The scattering surface size was approximately 4.5 square meters (6 meters x 0.75 meters). The Wideband Radar System described by Rao and Stevens (URSI 1989 Symposium San Jose, CA) was used to conduct these measurements.

Both vertically and horizontally polarized signals were transmitted. The receiver antenna polarization was varied from 0 degrees to 360 degrees in each case. As the receiver polarization was varied, the power levels changed considerably. Values 7 dB below the peak level were observed for vertical transmission, and decreases greater than 10 dB occurred for the horizontal case. The locations of these minima were in reasonable agreement with analytical predictions of Papa, Lennon, and Taylor (IEEE Transaction on Antennas and Propagation Vol. AP-34 No. 10 October 1986.)

These observations are the first microwave frequency results to indicate that varying the linear polarization of a bistatic receiving antenna can optimize (either maximize or minimize) the diffuse power scattered by a rough surface.

A BISTATIC POLARIMETRIC RADAR CROSS-SECTION MEASUREMENT AND IMAGING FACILITY

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The bistatic polarimetric radar cross-section measurement facility at the University of Texas at Arlington Wave Scattering Research Center has been used to measure radar cross-sections of and to image both deterministic and statistical targets. The measurement facility operates over a bandwidth of 4-18 GHz and VV,HH,VH, and HV polarizations. 4 transmit horns and 27 receive horns, strategically located over a spherically-shaped wall section of the chamber, make possible a variety of bistatic measurement combinations. In this presentation we will discuss the design of the chamber, including the r.f. components, and present graphs and images resulting from measurements of slightly rough and very rough conducting surfaces, dense volume scattering media, and model aircraft. Further, we will discuss calibration and sampling techniques, and show comparisons of measurement and theory to show the level of precision attainable with this facility.

Tuesday PM
URSI-B Session 39
Numerical Methods - Finite Difference Time Domain Methods

Chairs: Allen Taflove, Northwestern University; K. Kunz, The Pennnsylvania State University

Room: W-107 *Time*: 1:15-4:40

MODELING OF THIN DIELECTRIC CRACKS USING THE FINITE-DIFFERENCE TIME-DOMAIN TECHNIQUE

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Abstract

The problem of modeling a dielectric slab, backed by a perfect conductor and containing a crack in the dielectric material presents a challenge when using any electromagnetic technique. This difficulty arises from the relatively complex field distribution in the vicinity of the crack- particularly that of the tangential electric field. These fields exhibit severe localized perturbations from their smooth behavior away from the crack due to the collection of bound charges across the crack. The bound charge distribution can be thought of as arising from the disruption of polarization currents flowing within the dielectric material since the crack presents an open circuit to these currents.

In this presentation, a FD-TD technique for analyzing this type of structure using a spatial grid much larger than either the slab or the crack dimensions is presented. Using this approach, both near- and far-field scattering results can be obtained at great CPU and storage savings as compared to the "brute force" method of using a spatial grid small enough to directly resolve the small dimensions of the scatterer. Equations for advancing the electric and magnetic fields for cells that contain very thin dielectric slabs, conductor-backed slabs, and conductor-backed slabs with cracks are presented. In each case, a model of the near-fields associated with the particular sub-geometry is identified, and then build directly into the field-advance equations.

Results using this "smart cell" approach for 2- and 3- dimensional plane wave scattering by dielectric slabs and conductor backed dielectric slabs are presented and compared with both "brute force" FD-TD and method of moments calculations. Results of scattering by 2-D conductor backed dielectric slabs with cracks using a large spatial grid are also presented and compared with fine grid FD-TD results.

FD-TD ANALYSIS OF APERTURE ANTENNAS: OPEN-ENDED WAVEGUIDES, HORNS, AND PARABOLIC REFLECTORS

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This paper continues previous research in finite-difference time-domain (FD-TD) analysis of radiating structures. The paper consists of two parts. The first part reports studies of two-dimensional, electrically-large (~$50\lambda_0$) parabolic reflectors, illuminated by point sources and horn antennas. The resulting far-field patterns are compared with those generated by the geometric theory of diffraction (GTD.) The location of the feed antenna along the axis of the parabola is varied, and the results are examined.

The second part considers radiation by three-dimensional, open-ended waveguides and horn antennas. Where possible, FD-TD results are compared with results generated by the method of moments (MoM.)

ELECTROMAGNETIC CHARACTERIZATION OF SHIELDED MULTICONDUCTOR MICROSTRIP-LINE DISCONTINUITIES USING THE TIME-DOMAIN FINITE-DIFFERENCE METHOD(*)

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The time-domain finite-difference(TD-FD) method is applied to obtain the frequency-dependent characteristics of shielded multiconductor microstrip-line discontinuities. Numerical absorbing boundary conditions are customarily introduced to truncate the computational domain in the direction of wave propagation. To bypass the use of such conditions, we consider a nonlinear coordinate transformation in the direction of the axis of the transmission line. This transformation allows us to bring the surface at infinity to a finite distance from the discontinuity, so that no absorbing boundary conditions need to be applied. Choosing a fixed space increment in the transformed domain, this transformation procedure is shown to be equivalent to the implementation of a position-dependent propagation velocity that goes to zero as the surface at infinity is approached. The efficiency of the transformation, and its effect on the overall numerical dispersion and the accuracy of the solution are discussed.

To characterize the frequency-dependent behavior of the discontinuities, the techniques presented in (X.Zhang & K.Mei, MTT-36, pp.1775-1787, Feb.88) are used. A Gaussian pulse is used as the excitation and the reflected, transmitted, and coupled pulses on the various lines are used for the calculation of the frequency-dependent elements in the scattering matrix representation of the discontinuity. In order to correctly specify the frequency range of applicability of the results, the cutoff frequencies of the higher-order modes of the structures under consideration need to be found. This is done by a two-dimensional application of the TD-FD method over the cross-section of the multiconductor transmission line, based on the simple observation that modes at cutoff are characterized by the fact that $\partial/\partial z = 0$ where z is the direction of propagation along the axis of the line.

(*) Research supported in part by the Semiconductor Research Corporation.

CHARACTERIZATION OF ELECTROMAGNETIC FIELD IN ELECTRICALLY DENSE LAYERS

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This paper explores the structure of electromagnetic fields inside and in the near field of layered cylindrical and spherical scatterers using eigenfunction expansion techniques. The objective is to derive simple mathematical equations to model the field variations so that both Faraday and Ampere contour calculations are accurate. It is shown how these validated models can be used to generate modified FD-TD cells so that a layered scatterer can be accurately modeled using a uniform grid mesh.

CONFORMABLE FDTD MODELING OF ELECTROMAGNETIC SCATTERING AND INTERACTION

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The FDTD method has been used in the modeling of many kinds of electromagnetic phenomena, including scattering, radiation, particle accelerators, biological interaction and holography. Until recently the surface of a modeled object which did not lie directly on the Cartesian FDTD grid was approximated with stepped edges. Conformable FDTD modeling overcomes this problem. In this paper the comformable FDTD modeling of two and three dimensional objects is discussed and results are presented.

The starting point of the conformable FDTD algorithm is Ampere's and Faraday's laws, shown here

$$\oint_C \vec{H} \cdot d\vec{l} = \iint_S \sigma \vec{E} \cdot d\vec{S} + \frac{\partial}{\partial t} \iint_S \vec{D} \cdot d\vec{S} + \iint_S \rho \vec{v} \cdot d\vec{S}$$

$$\oint_C \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \iint_S \vec{B} \cdot d\vec{S}$$

The contours of Ampere's and Faraday's laws intersect each other's enclosed surface in much the same way as the links in a chain intersect. Contours not near a medium interface are rectangular and, upon the numerical approximation of their contour integrals, result in finite difference equations identical to the traditional curl equation based FDTD algorithm. Near a medium interface the normally rectangular Faraday contours surrounding each H component are deformed so as to conform to the surface. Each H component is assumed to represent the average value of the magnetic field within the patch bounded by the the distorted contour. The electric field, E_{tan}, on the distorted contour at the object surface is assumed to be zero for perfect conductors or for dielectrics is computed via an auxiliary Ampere contour. Along the remaining straight portions of the contour, the electric field components are assumed to have no variation along their respective contour segments. Where possible these electric field components are calculated using rectangular Ampere contours from adjacent H components. The Ampere contours are not deformed. Also, calculations of (non-auxiliary) Ampere contours which cross the media boundary are not used.

TIME-DOMAIN SIMULATION OF PLANAR TRANSMISSION LINES

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ABSTRACT

Planar transmission lines are the essential elements of microwave and millimeter-wave integrated circuits. Analysis, modeling, and design of these planar transmission lines are important. Several methods are presently available for the analysis of those lines.

In this paper, we will discuss basic procedures and key issues in the time-domain analysis of planar transmission lines. The time-domain simulation is a very general and useful approach. No specific modes on the lines or surface currents are assumed; information over a wide frequency range can be obtained by a single calculation. It is easier to analyze anisotropic media in comparison with frequency-domain methods. In the time-domain finite-difference method, one first finds propagating waveforms along transmission lines which are excited by Gaussian pulses, then obtain frequency-domain parameters by using the Fourier transformation. Critical steps, such as pulse excitation of the lines and boundary treatment of the computation domain, will be illustrated. Results on coplanar waveguides, coplanar striplines, slotlines, inverted lines, and suspended lines will be presented. Those include spatial and time waveforms, voltage and current distributions, dispersion relations, and characteristic impedances. Comparisons of these simulated results with available experimental data and theoretical results obtained from other methods are carried out. In addition, we will discuss transverse response phenomena of inverted and suspended lines.

A Numerical Back–Projection Method Using Minimal Field Knowledge†

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It is often the case in EM problems that one knows the fields at points far from a source and would like to know the value of the fields near the source. This so–called back–projection problem is often untenable due to both its mathematical formulation and the need for complete field information on a closed surface. A new method is proposed which, given an accurate knowledge of the source geometry, allows projections to any point in space and requires fields to be known only at one or a few positions.

In systems such as wire antennas, the radiating source may be characterized by a single function such at the current at the base of the antenna. This antenna can be modeled with EM simulation software such as FDTD and, using far–field projection methods, the resultant fields at the experimental sample points may be projected. Also, fields can be projected to the positions in space where the EM fields are not measured. For linear systems, one can then derive transfer functions from the points in space where fields are known to the points in space where field information is desired. In such systems then, only a numerical model of the source and a single far–field field value is required to predict field values anywhere in space.

If the antenna can not be characterized by a single drive function, the method can be generalized. For example, in the case of a multi–mode wave–guide fed system, the strength of each mode versus time is needed to characterize the antenna drive. The method described above can be easily extended to this case so that the number of far–field measurements must only be equal to the maximum number of modes in the guide. The fields in all space can once again be predicted, *including the mode strengths within the actual drive antenna.* This method therefore is also a powerful diagnostic tool revealing the complex internal behavior of radiating systems given only a few easy to make far–field measurements.

The method will be fully developed and demonstrated with LLNL's FDTD modelling code TSAR. Comparisons to experiment and analytic solutions will be presented.

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†This work was performed by the Lawrence Livermore National Laboratory under the auspices of the U.S. Department of Energy under contract No. W-7405-ENG-48.

THE ACCURACY OF WAVE SOLUTIONS WITH THE FINITE-DIFFERENCE TIME DOMAIN METHOD

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The accuracy with which the finite-difference time domain (FDTD) method calculates wave solutions is a function both of the ratio of the time interval to the space interval and also of the direction in which the wave travels. This accuracy can be described by the accuracy in the velocity calculated for plane waves (and in two dimensions line waves). The resulting accuracy with which FDTD calculates resonant frequencies of resonators is calculated directly for rectangular resonators in two dimensions and interpreted with the general velocity relation. Numerical results are calculated for non-rectangular bodies.

Highest accuracy is shown to result from use of the largest time interval consistent with stability. Least accuracy results from use of small time intervals. Because use of very small time intervals is equivalent to solution of Helmholtz's equation, the conclusion is that FDTD with maximum time interval produces more accurate results than use of the finite-difference method on Helmholtz's equation. This fact is shown directly for rectangular bodies and is also demonstrated with numerical calculations on non-rectangular bodies.

The relation of this result to the accuracy of the transmission-line-matrix method (TLM) is discussed briefly.

AN INVESTIGATION OF THE ACCURACY AND EFFICIENCY OF THE FINITE-DIFFERENCE TIME-DOMAIN METHOD

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The finite-difference time-domain method has been successfully applied in the past to various types of radiation and scattering problems. In this paper this method is applied to the geometry shown in Fig. 1. The dipole antenna is embedded in the dielectric material that fills the trough region on a finite flat conducting plate. We are interested both in analyzing the radiation pattern of the antenna in this environment, and in understanding the scattering properties of this structure when illuminated by a plane wave.

This paper addresses two issues related to application of the finite-difference time-domain approach to general scattering and radiation problems, by using the geometry described here as an example. The first of these, is the accuracy of the radar cross-section and radiation patterns computed using the finite-difference method. Results obtained using the FDTD approach are compared to other methods to establish guidelines for the discretization density required, and the accuracy to be expected for complex geometries.

The second topic addressed in this paper is the efficiency of the FDTD approach for steady state (single frequency) problems. If one wishes to compute the monostatic radar cross-section, the computation time is directly proportional to the number of look angles desired, because the computations need to be repeated for each look angle. Similarly, if the radiation patterns of the antenna or the radar cross-section of the structure for a range of frequencies is desired, one has to repeat the computations for each frequency of interest. One might conjecture that if the results for a given look angle has been obtained, using these converged result as the initial value to compute the results for the next one would achieve a faster rate of convergence. It is demonstrated that this is indeed the case for both the radiation and scattering problems, provided that the two look angles are sufficiently close to each other. Furthermore, the same approach is found to be useful for frequency scanning as well. Results for both frequency and spatial scanning computed using this approach will be presented in the paper.

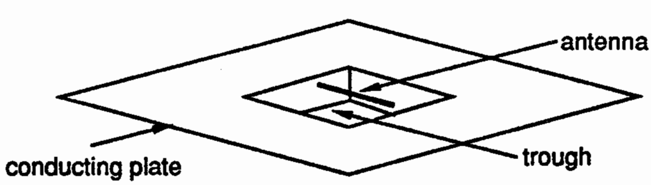

Fig. 1 Geometry of an antenna residing in a trough filled with possibly lossy dielectric material.

Tuesday PM
URSI-B Session 44
Guiding Structures II

Chairs: David A. Hill, United States Department of Commerce; Hassan A. Kalhor, State University of New York

Room: W-102 *Time*: 1:15-5:00

REAL AND COMPLEX MODAL SOLUTIONS FOR LOSSLESS MULTI-LAYER STRIPLINES

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David R. Jackson
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Houston, TX 77204-4793

For many lossless multi-layer stripline structures, we have identified two dominant mode solutions. The first is the expected TEM/quasi-TEM mode which has a purely real propagation constant. The propagation constant for the second mode, however, is complex, corresponding to a mode which propagates along the strip but *leaks* energy into the dominant parallel plate modes of the structure. This mode behaves as a classical leaky wave mode; therefore, the modal fields will attenuate with distance along the transmission line – attenuation which is not associated with conduction loss. The complex dominant mode solution is a result of the capture of the pole, in the spectral domain integration, which corresponds to the dominant *TM* parallel plate mode. Although the propagation characteristics of the real and complex dominant modes are different, the current distributions are very similar. This implies that the fields near the strip, corresponding to these different modal solutions, are also similar; therefore, suggesting that these modes can be excited in a like fashion. One structure which supports the leaky mode is the stripline with a small air-gap above the center conductor. In the practical realization of many simple striplines it is difficult to eliminate these small air gaps, which often result in unexpected and frustrated transmission line performance. The existence of the dominant leaky mode may help quantify many of these practical problems.

In our presentation we will discuss the development of a general algorithm for the analysis of a multi-layered stripline, based on standard spectral domain techniques, and we will detail the air gap problem and discuss other structures with leaky mode solutions. In our analysis of the general stripline, we derive a multi-layer dyadic Green's function and use it in a coupled integral equation expression for the current induced on the thin, perfectly conducting strip. The cross-sectional geometry and the electrical parameters of the layers are assumed to be arbitrary. The current on the strip is expanded as a sum of cosine-Maxwell functions and solved for using a Galerkin method of moments procedure. The various modal propagation constants are determined by finding the roots of the resulting matrix equation.

FULL-WAVE INTEGRAL OPERATOR ANALYSIS FOR CHARACTERISTIC IMPEDANCE OF MICROSTRIP TRANSMISSION LINES

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The characteristic impedance of microstrip transmission lines is a design parameter of considerable practical interest due to the extensive use of the microstrip configuration in micro/mm-wave integrated circuits. As the operating frequency becomes high, an accurate full-wave evaluation of dispersion characteristics and characteristic impedance are essential to the analysis of microstrip circuits. The dispersion characteristics of both single and coupled microstrip lines have been studied by the authors, by using a rigorous full-wave integral equation description of microstrip environments [Y. Yuan and D. P. Nyquist, 1989].

In this paper, we present a rigorous full-wave integral equation analysis for the characteristic impedance of microstrip transmission lines. The electric field integral equation system, which is based on an electric dyadic Green's function for the layered IC environment, is solved by Galerkin's moment method with Chebyshev polynomial basis functions. Consequently the eigenmode currents on the strips are obtained, along with the propagation eigenvalue, in a compact quasi-closed form as a rapidly convergent Chebyshev series. The power/current definition of characteristic impedance is adopted here for the microstrip lines, that is $Z_0 = 2P_{ave}/I_0^2$ for a single line and $Z_0 = P_{ave}/I_0^2$ for two identical coupled lines, where I_0 is the total z-directed strip current. The average power is calculated as (CS = infinite cross section)

$$P_{ave} = \frac{1}{2}\,\mathrm{Re}\iint_{CS}(E_x H_y^* - E_y H_x^*)dxdy$$

where the fields are given in terms of the Green's function and the eigenmode currents. Since no prior knowledge of the current density on the strips is necessary, this method is particularly suitable for analyzing the coupled microstrip.

Numerical implementation for the microstrip lines is developed. Convergence of the characteristic impedance is investigated. Numerical results for different configurations are obtained. The frequency dependence of characteristic impedance is presented and comparison is made with the results available in the literature.

CLASSIFICATION OF MODE TYPES ON INTEGRATED MICROSTRIP TRANSMISSION LINES

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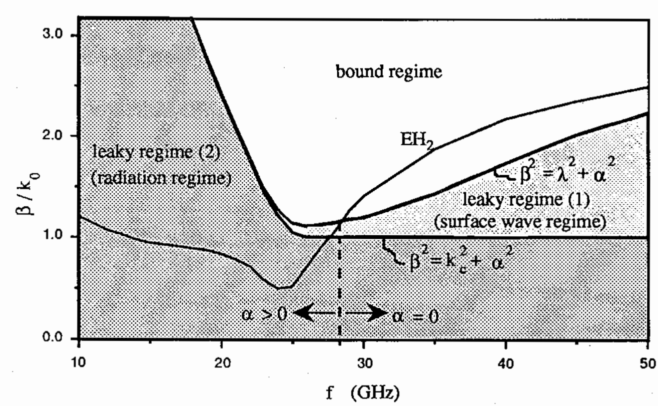
Increasing attention has focused on propagation characteristics of higher-order modes on open integrated microstrip transmission lines. This is in large part due to the existence of interesting and potentially useful non-TEM properties of these modes. This includes the possibility of mode leakage into the dielectric film layer in the form of surface waves and excitation of radiation into the (unbounded) cover medium.

Several techniques have been advanced and utilized in the description and analysis of such modes, and some natural confusion has resulted from use of differing techniques, notations, and terminology.

In this paper a natural and intuitive classification scheme for higher order modes on integrated microstrip structures accounting for their leakage and radiation characteristics is presented. This technique is based on a rigorous formal solution to Maxwell's equations incorporation boundary conditions in other full generality. The resulting dyadic integro-differential equation includes a two-dimensional inverse Fourier transform on spatial frequency variables corresponding to the spatial variables (x and z) of the plane of the ground plane/film layer background medium.

The inversion contour for the x-spatial frequency variable ξ is nominally chosen as the real axis; however, caution must be exercised due to the presence of simple pole and branch point singularities of the integrand in the complex-spatial frequency (complex ξ) plane.



A diagram showing the three propagation regimes.

Commission B

DOMINANT MODE CHARACTERISTICS OF THE ASYMMETRIC SLOTLINE

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Single-sided slotlines have been in use for quite some time as transmission lines and circuits. More recently, however, slotlines are being increasingly utilized in the development of wideband microwave and millimeter-wave antennas. A microstrip-to-slotline or a coaxial-to-slotline transition is often needed to couple energy from the input transmission line to slotline feeding the slotline antenna. One is often faced with the difficulty of fabricating very narrow slots for the feeding slotline in order to obtain a good impedance match with the input line. To overcome this and other problems associated with the single-sided slotline, the use of an asymmetric slotline, in which the current-carrying conductors are placed on opposite sides of the dielectric substrate has been suggested. This structure has been recently used in the design of wideband feeds for the tapered slot antenna. However, no theory yet exists for obtaining the basic guided-wave parameters of the asymmetric slotline. In the present investigation we are concerned with the propagation of the fundamental mode on the asymmetric slotline.

Fig. 1 shows the cross-section of the asymmetric slotline. It consists of two semi-infinite conductors placed on opposite sides of a dielectric substrate of thickness $t = 2d$ and having a relative permittivity ϵ_r. Due to the inherent dielectric inhomogeniety of the structure, the guided wave will be non-TEM in nature and suffers dispersion. Placement of conductors on the opposite sides of the substrate allows one to bring the two edges arbitrarily close to each other in the lateral direction. One may then have overlapping or non-overlapping conductors resulting in a wide range of impedances values. For the sake of analytical simplicity, we place conducting shields at distances d_o above and below the structure as shown in Fig. 1.

The problem is solved rigorously by the Wiener-Hopf technique. Numerical results will been presented for the effective dielectric constant and characteristic impedance. Effect of the conducting shield on the dominant mode characteristics will be shown.

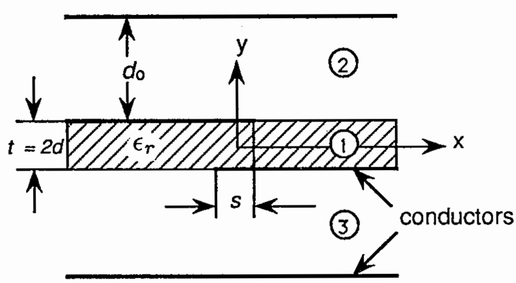

FIG. 1

MODE TRANSITIONS IN DUAL MICROSTRIP ON SAPPHIRE AND EPSILAM-10 SUBSTRATES

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It has been found that transitions exist between the fundamental quasi-TEM mode in shielded microstrip and the higher-oder modes with a uniaxially anisotropic substrate where $\epsilon_\perp > \epsilon_\|$, an example being Epsilam-10 ($\epsilon_\perp = 13.0, \epsilon_\| = 10.3$). In the transition region there appears to be a mode interchange, where for higher frequencies the largest eigenvalue is not associated with the quasi-TEM mode. Modal transitions also occur between the higher-order modes. This work stemmed from recent presentations of a potential radiation effect in the dominant mode of open microstrip with an Epsilam-10 substrate (M. Tsuji et. al., 1989 IEEE MTT-S Digest, 783-786), and in slotline and coplanar waveguide with isotropic substrates (H. Shigesawa et. al., 1988 IEEE MTT-S Digest, 199-202).

In light of these recent findings, such effects in shielded coupled microstrip on an anisotropic substrate have practical integrated circuit implications. The work presented here is an investigation of mode transition effects in dual coupled microstrip on Epsilam-10 and sapphire ($\epsilon_\perp = 9.4, \epsilon_\| = 10.6$). Since the even mode in dual microstrip is similar to the single strip mode, one expects to find a somewhat similar transition effect as in the single strip case, resulting in modified inter-line coupling characteristics. With sapphire, on the other hand, it is not expected that there would be such a transition effect for the even mode, but rather for the odd mode, due to the fact that $\epsilon_\perp < \epsilon_\|$.

The importance of this work becomes clear when one considers the effect of crosstalk in multiple stripline geometries on anisotropic substrates. Data will be presented in the form of computed dispersion curves and field plots illustrating the mode coupling phenomenon with Epsilam-10 and sapphire substrates. Results are verified through the use of a spectral domain formulation and a variational weak-form formulation for the vector magnetic field, with a finite element solution.

QUASI-STATIC ANALYSIS OF A TWO-WIRE TRANSMISSION LINE LOCATED AT AN INTERFACE

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Propagation along a single wire (J.R. Wait, Radio Sci. 7, 675-679, 1972) or multiple wires (E.F. Kuester, D.C. Chang, and S.W. Plate, Electromagnetics 1, 243-265, 1981) located above the earth has been studied thoroughly, and the appropriate mode equations have been solved numerically to determine the complex propagation constants. In this paper we analyze a two-wire transmission line located at the air-earth interface and derive simple quasi-static expressions for the complex propagation constant, the characteristic impedance, and the field distribution of the differential mode. Both the complex permittivity and permeability of the earth are allowed to differ from that of free space. The half-space geometry is found to be equivalent to a homogeneous medium with effective permittivity and permeability that are consistent with static image theory. A numerical solution of the general mode equation shows that the quasi-static results are valid when the wire spacing is electrically small.

The quasi-static results have application to the in-situ measurement of the complex permittivity and permeability of various soil types and magnetic materials. Simple expressions are derived for both the complex permittivity and permeability in terms of the measured propagation constant and characteristic impedance. For the simpler case of a nonmagnetic earth, the complex permittivity can be determined from a measurement of either the complex propagation constant or the characteristic impedance.

How To Describe Quantitatively Hybrid Modes in Generalized Transmission Lines ?

Ke WU

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In recent MMIC's/MIC's and dielectric/optical waveguides, hybrid structures receive more and more attention. However, it is very difficult to convey field polarization in those structures, due to the hybrid mode nature, in a simple and a comprehensive form without resorting to an expensive and heavy graphic description.

To solve this problem, we introduce in this paper four easy-to-read normalized Polarization Coefficients (PC) based on LSE/LSM eigenmode coupling in the power formulation (K WU, Ph.D Thesis, Grenoble, France, pp.60-66). This theory considers the fact that the field quantities are directly related to the four coupling coefficients (δ_{hh}, δ_{ee}, δ_{eh}, δ_{he}, *with* $\delta_{hh} + \delta_{ee} + \delta_{eh} + \delta_{he} = 1$) *This approach is very useful to interpret the propagation behavior and to distinguish different modes in hybrid structures On the other hand, it is possible to define relative criteria of hybrid modes, for example, how and when can we call a hybrid mode as the quasi-TEM ? This technique may represent a major breakthrough in the concept of field polarization and extend our knowledge regarding field description.*

Fig.1 shows some typical behavior of the polarization coefficients (PC) for a sandwiched coupled microstrip ($w = 0.2$ *mm*, $t_2 = 2\ t_1 = 0.254$ *mm*, $\varepsilon_r = 2.22, f = 33$ *GHz).*

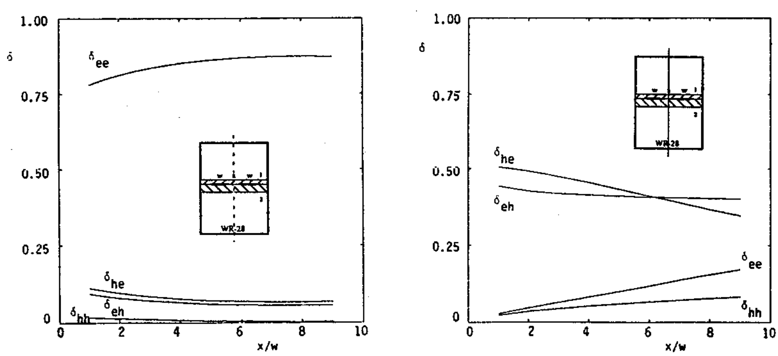

Fig.1 : Polarization Coefficient (PC) behavior of the sandwiched coupled

COMPLEX MODES IN HOMOGENEOUS CORRUGATED WAVEGUIDES

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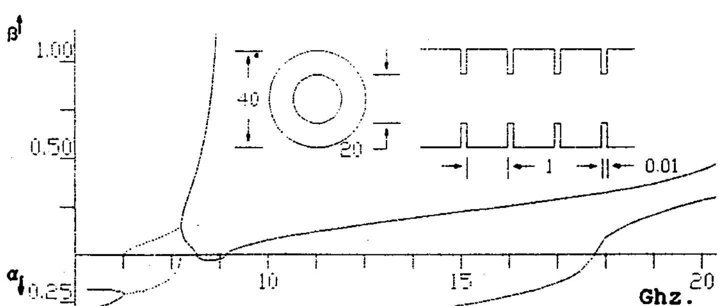
In this communication corrugated waveguides are analyzed, by means of the rigorous mode matching technique. The computed dispersion curves for circular and rectangular corrugated waveguides are presented.

The method of analysis is based on breaking down the corrugated waveguide into smooth-wall waveguides segments. The discontinuities between those segments are modeled by multimode admittance parameters computed by the mode matching technique (F. Alessandri et al., IEEE. MTT., Vol.36, No.2). Imposing Floquet's theorem on one period a general eigenvalue matrix equation is derived.

After some algebra this eigenvalue equation is rewritten as a polynomial with real coefficients that is solved efficiently for the eigenvalues (propagation constants of the eigenmodes) with the well suited Müller method.

As an example, the figure shows the computed dispersion curves for the first modes of a circular corrugated waveguide. For this geometry not only normal and backward waves have been obtained (compare with: P.B.J. Clarricoats & P.K. Saha, Proc.IEE., vol.118, No.9), but also complex waves.(modes with both real and imaginary part on the propagation constant) as already predicted by (D.N. Cooper, Electron. Lett. Vol.7, Nos.5/6). Complex modes have also been obtained for other geometries with deep corrugations, as in double plane rectangular corrugated waveguide.



Dimensions in mm.

Microstrip Line with Imperfect Conductor Strip of Finite Thickness

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The phase and attenuation constants of a microstrip transmission line with imperfect conductor strip of non–zero thickness is investigated by using the boundary element method. The structure is composed of three homogeneous regions: namely, the air, the lossless dielectric, and the imperfect conductor. By using Green's theorem and (H_x,H_y) formulation, the field components in each homogeneous region can be expressed as functions of the transverse magnetic fields and their normal derivatives along the boundary. The boundary conditions are enforced by requiring the total magnetic fields and the longitudinal electric field be continuous across the interface of the adjacent regions. Then, an eigenvalue equation for the complex propagation constant can be formulated and the resultant eigenvalue and eigenvector provide the information for the conductor loss and the field distributions. Instead of solving the eigenvalue equation by the iterative root–searching in a complex plane, a one–dimensional searching along the real axis is utilized by noticing the fact that the attenuation constant is relatively small in comparison with the phase constant. This approach has the advantage that the associated Green's functions contain the Bessel functions of real argument, thus the calculations may be made simpler.

In this paper, the effect of the strip thickness and the dielectric substrate will be examined by a study of the propagation constant and the field distribution. Comparison is also made of the computed results with the conventional perturbational ones where lossless fields and zero conductor thickness are assumed.

APPLICATION OF MATHIEU FUNCTIONS FOR PERIODIC SLOW-WAVE STRUCTURES

Dr. V. Dzougaev* and Dr. N. Ivanova

While analyzing electromagnetic wave propagation in so-called "flat" slow-wave structures having only one cross size, which is much larger than the other one, it is interesting to study the application of an elliptic cylindrical system of coordinates as well as the theory of Mathieu functions. Mathematical theory mentioned above has not been sufficiently used in electronics and microwave technique yet. In particular, calculations concerning electromagnetic wave propagation in some types of flat slow-wave structures by means of elliptic cylindrical systems and Mathieu functions have not been investigated analogically yet. With the help of this theory the authors have studied the dispersion properties of a slow-wave in a line of "meander" type without a screen as well as with a screen of elliptic form, helixes with elliptic cross-section based on the models of a tape helix and a cylinder with a conducting helix. Dispersion characteristics for particular cases of a tape helix as well as for a system of "zigzag" type have been computed for the first time. The equivalent characteristic wave impedances, coupling coefficients for an elliptic helix and elliptic electron flow have been computed on the base of the model of spirally conducting cylindrical surface. It has been shown that if we compare a round helix at a fixed frequency, optimal in accordance with the coupling coefficient and equal winding angle, it becomes evident that the square of cross-section and elliptic spiral perimeter with an accentricity of 0,98 are approximately twice as large as those for a round helix. This result allows us to make a conclusion concerning the perspectiveness of use of a helix with an elliptic cross-section for displacement of working band in the direction of short wave length instead of a round one in a travelling-wave tube.

The authors have also investigated the system consisting of a ring-bridge connection type line of an elliptic cross-section with an accentricity close to I. There is a flat meanderline displaced relatively to the ring bridge connection type line inside it. Maximum transitions of ordinary and modified Mathieu functions have been considered. It has been shown that zero harmonic slow-wave factor in such a system can increasingly exceed slow-wave factor of a single meander. Such system should be useful for microwave integrated circuits.

Tuesday PM

Joint AP-S, URSI-B Special Session 45

A Tribute to Professor L. B. Felsen

Chairs: Alex Cullen, University College London; J. M. Arnold, University of Glasgow

Room: W-105 *Time*: 1:15-5:00

1:20⁺	**Hybrid Ray-Spectral Asymptotic Methods** J. M. Arnold*, University of Glasgow	236
2:00	**Alternative Representations of Green's Functions for the Scalar Wave Equation through the Characteristic Green's Function Method** L. W. Pearson*, McDonnell Douglas Research Laboratories; K. A. Michalski, Texas A&M University	237
2:20	**On Ray and Beam Expansions for Analyzing EM Coupling into Open-Ended Waveguide Cavities** Prabhakar H. Pathak*, Robert J. Burkholder, The Ohio State University	AP-S
2:40	**Phase-Space Concepts in Asymptotic Wave Theory** Ioannis M. Besieris*, Virginia Polytechnic Inst. & State Univ.	238
3:00	**Coffee Break**	
3:20	**Phased Space Beam Summation of Transient Radiation for Large Distributed Apertures** B. Z. Stienberg*, Ehud Heyman, Tel-Aviv University; L. B. Felsen, Polytechnic University	239
3:40⁺	**Wavefronts, Resonances, and Target Identification** D. G. Dudley*, The University of Arizona	240
4:20	**Relationship Between Pulse Response Waveforms and Shapes of the Scatterers** Masahiko Nishimoto, Hiroyoshi Ikuno*, Kumamoto University	AP-S
4:40	**Hybrid Wavefront Resonance Representation for Transient Scattering by an Open Cavity** Gershon Friedlander, RAFAEL; Ehud Heyman*, Tel-Aviv University	241

HYBRID RAY-SPECTRAL ASYMPTOTIC METHODS

J. M. Arnold

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Asymptotic methods for the analysis of complex high-frequency wave-propagation problems have proved extremely successful in recent years. When based on geometrical optics, asymptotic methods are capable of describing a very wide range of phenomena which are simply insoluble by classical exact methods such as the separation of variables. Nevertheless, the basic techniques of geometrical optics are insufficient to encompass all asymptotic wave phenomena; typically, geometrical optics encounters regions of space where it predicts infinite or nondifferentiable fields, and these regions are generally associated with transition phenomena where the underlying asymptotic nature of the field undergoes a qualitative change. A major concern of the development of these techniques has been the provision of uniform representations for transition fields while retaining the basic simplicity and insight of elementary geometrical methods.

The predictions of GO field values are given in terms of elementary functions which are pointwise in the configuration space; on the other hand, transition fields require the configuration space fields to be expressed as integrals which cannot generally be reduced to simple pointwise local values. The archetype of the transition region is the much-studied simple caustic formed as the envelope of a system of rays, separating a region in which two rays pass through each point from one where no rays exist. The uniform transition function in this case is well-known to be the Airy function, having a small argument when the observation point lies near the caustic in configuration space.

Thus, one is frequently required to employ hybrid constructions of asymptotic field representations, where GO suffices in many regions, but must be supplemented by more complicated formulae in other regions. The natural question arises as to whether one might actually transform a nonuniform GO representation directly into a more uniform one, using only the GO data already available. It is now understood, from several different viewpoints, that the accomplishment of this objective requires the introduction of a spectral representation of the field which is in some sense 'conjugate' to the GO representation. The parameters of the spectral representation are determined by the ray geometry, and the spectral superposition which returns from spectral space to configuration space achieves the smoothing required to render the field asymptotically uniform.

Several examples of this idea have now been identified, and thoroughly studied. In diffraction problems involving apertures in screens, the GTD can be formulated in the spectral domain formed by the representation of the field as a superposition of plane waves; the construction of the complex amplitudes of the plane waves follows a method identical in character to conventional space-domain GTD, and spectral integration produces the required uniform transition integral. This approach can also be shown to convey significant advantages in numerucal computation, because the FFT algorithm can be exploited in performing the spectral superposition. In guided-wave problems, the field in the guide at large distances from the source consists of contributions from a very large number of rays which may themselves carry nonuniformities due to caustics or lateral waves excited at total internal reflections in a waveguide boundary. By a suitable parametrisation of the rays, the Poisson sum formula transforms the slowly convergent nonuniform ray representation of the field in the guide into a rapidly convergent uniform representation as a sum of modes. If only a subset of rays is subjected to Poisson transformation, then a subset of modes represents the field, with precise geometrical relationships between the ray- and mode-species connected by the transformation.

ALTERNATIVE REPRESENTATIONS OF GREEN'S FUNCTIONS FOR THE SCALAR WAVE EQUATION THROUGH THE CHARACTERISTIC GREEN'S FUNCTION METHOD

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Krzysztof A. Michalski, Electromagnetics and Microwave Laboratory, Department of Electrical Engineering, Texas A&M University, College Station, TX 77843

The Characteristic Green's Function Method (CGFM) and the alternative Green's function representations that ensue from it are the unifying feature in all of Felsen's contributions to field representation theory. The CGFM reduces a separable, scalar, two- or three-dimensional, partial differential equation (PDE) Green's function problem to an ordinary differential equation Green's function problem by reducing the derivative operator(s) in all but one of the variables to an algebraic quantity. At the outset, one chooses one coordinate as the "transmission" direction in terms of which the final ODE Green's function equation is to be couched. The differentiations associated with the remaining coordinate or pair of coordinates are transformed out of the PDE by expressing the PDE Green's function in terms of eigenfunctions associated with the "transverse" coordinates. Alternatively, the eigenfunction representations can be expressed as integrals of Green's functions associated with the ODEs obtained by separating the original equation. The rich collection of alternative representations stems from the freedom to choose any given coordinate as the transmission coordinate and to choose either the eigenfunction or Green's function integral representations in the transverse direction. Analytic function methods provide a vehicle for converting one representation to another and for obtaining hybrid representations with attractive convergence properties.

In this presentation, we illustrate the fundamental features of the CGFM in a transparent fashion by addressing the free-space Green's function in the cartesian coordinate system. The conversion among representations is straightforward, and relative merits of alternative representations are easily distinguished. The Green's function of an impenetrable circular cylinder is addressed as a second example. By employing the CGFM with the angular coordinate as the transmission variable, one obtains *ab initio* an integral representation that can be converted through integration path deformations either to the conventional angularly periodic Green's function representation or to the so-called creeping-wave series.

PHASE-SPACE CONCEPTS IN ASYMPTOTIC WAVE THEORY

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Uniform asymptotic methods are those which are applicable on and beyond caustics and are necessary whenever the difficulties caused by caustics must be overcome. All uniform asymptotic methods are obtainable by representing wave propagation problems in "classical" phase space (a joint space/time - wavenumber/frequency domain), where the "classical flow," being "incompressible," can be depicted by nonintersecting phase-space rays. Such a realization, in a form invariant by canonical transformations of phase space, exhibits the unity of all available methods.

Uniform asymptotic expansions are subjects of active research which is being pursued by a variety of mathematical techniques, e.g., Maslov's theory of of perturbations, Feynman's phase-space path integral approach, the Weyl-Wigner-Moyal phase-space formalism and the beam superposition method. Additional significant contributions along these lines have been made recently by Arnold, who extended Maslov's theory in order to account for a fully diffractive (possibly) lossy environment, and Felsen and Heyman who first eliminated the paraxiality restriction in the original beam method through space complexification and then extended the technique to the time domain through complexification of both space and time.

It is my intent in this talk to provide a tutorial overview of phase-space concepts in asymptotic wave theory. I shall also discuss briefly recent new results dealing with the possibility of achieving "super-squeezed" nonseparable wave packets by exploiting localization properties in phase space.

Phase Space Beam Summation of Transient Radiation from Large Distributed Apertures

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and

Leopold B. Felsen
Dept. of Electrical Engineering and Computer Science
Weber Research Institute, Polytechnic University
Farmingdale, NY 11735

Analysis and synthesis of transient fields radiated by distributed sources is facilitated and systematized by a simultaneous understanding of the space-time and wavenumber-frequency (i.e., phase space) behavior of the wave objects employed in the problem parametrization. Extending a previous study of time-harmonic fields [B.Z. Steinberg, E. Heyman and L.B. Felsen, submitted to J. Opt. Soc. Am.], the present investigation in the configuration-spectrum phase space is structured around alternative continuous integral forms that incorporate decomposition into elementary sources (space-time Kirchhoff representation), decomposition into plane waves (wavenumber-frequency spectral representation), or a combination of both. Passing from the configurational to the spectral domain, and vice versa, is accomplished via forward and inverse Fourier and Radon transforms. To gain the flexibility for arbitrary sequential reduction of the full multidimensional integrals, as required for alternative projections from the full phase space onto useful constrained domains, the time dependence is expressed via the theory of complex analytic signals. Insight into the "observable" fields generated by the distributed but abruptly truncated (i.e. edge-diffracting) aperture sources, especially in the range of high-frequency spectra, is furnished by asymptotic techniques that establish localization around constructively interfering wave groups. The asymptotic results have a cogent physical interpretation in terms of wavefront approximations, ray fields, pulsed beam (PB) fields and other collimating wavegroups whose basic features in and away from the aperture are poignantly schematized through confinement near special curves in the phase space. Attention is then given to embedding localization a priori into the full format, without recourse to asymptotic considerations. This is done by introducing window functions into the integrands, thereby giving rise in the analysis-synthesis procedure to windowed Fourier and Radon transforms. Now, PB propagators are generated inherently, their amplitude, initiation time, as well as location and direction in the aperture being determined by the local windowed spectral function. The connection between the windowed and asymptotic nonwindowed forms is explored to aid in the selection of "good" window functions. These concepts are illustrated and quantified on a specific numerical example for a pulsed truncated aperture distribution that generates nonfocused or focused fields and is subjected to an analytic delta function window.

WAVEFRONTS, RESONANCES, AND TARGET IDENTIFICATION

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The theoretical and computational aspects of target identification in electromagnetics have been under intense study since the introduction of the singularity expansion method (SEM) by Baum in 1971. Early studies were concerned with exploiting the SEM characteristics of a transient return from a scatterer. Unfortunately, such studies were only able to take advantage of the later time portion of the signal after the resonances of the body had become established.

This situation changed dramatically when L.B. Felsen became interested in the subject. Beginning with a 1982 workshop, joint between the United States and the Federal Republic of Germany, hosted by K.J. Langenberg, Felsen has consistently and correctly pointed out that, whereas the SEM representation may be a "natural" one for certain classes of scatterers, it is not necessarily the most "efficient" for target identification or classification. Indeed, because of his studies, both individual and in collaboration with E. Heyman, workers in target identification now realize that there are important links between wavefront and resonance representations of scattered signals. These issues were thoroughly explored in 1987 in AGARD Lecture Series No. 152, ***Theoretical Aspects of Target Classification***, L.B. Felsen, Director (available through NTIS, 5285 Port Royal Road, Springfield, VA 22161, USA).

In 1984, in order to explore the power of the concepts contained in the work of Felsen (and Heyman and Felsen), we incorporated the basic ideas into the dissertation research of K.A. Nabulsi (Department of Electrical and Computer Engineering, University of Arizona, 1984). In this work, the notions of wavefronts, resonances, and hybrids have been applied to the case of the lossless dielectric slab backed by a perfect conductor. This model allows us to examine both ray-optic and resonance solution forms as well as two hybrid forms.

We complete the discussion in this present paper by pointing out how the slab study reinforces Felsen's insistence on the importance of proper selection of parameters associated with a target. Indeed, intelligent parameter selection in many practical cases determines the efficiency of the target classification or identification process.

HYBRID WAVEFRONT RESONANCE REPRESENTATION FOR TRANSIENT SCATTERING BY AN OPEN CAVITY

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Abstract

Short pulse scattering signals furnish valuable information for classification or identification of radar signatures from irregularly shaped objects. The early time field conveys local information in form of the high frequency initial wavefront returns from local scattering centers. Returns at latter observations times convey global information in the form of complex resonances of the now fully illuminated target. These oscillatory contributions are usually highly damped, hence only few of them may actually be observed. An important class of target involves open-ended enclosures with interior-exterior coupling. Here distinct late time observables may be found in the form of high-Q resonances. Although the wavefront interactions around the exterior boundaries may, in principle, be described by the *global* resonances of the composite object, an *effective parametrization* is provided by separating the contributions from the *internal* and the *external* fields, expanding the former by means of the complex resonances while expressing the latter as multiple wavefront interactions. This furnishes a compact representation of the early time observables in terms of the rapidly decaying external ray interactions (that may easily accommodate external features) and of the late time observables in terms of the internal high-Q resonances.

These concepts are illustrated in this work, in which we calculate the time dependent scattered field for the prototype configuration of a finite-length plane parallel perfectly conducting waveguide, which is open at one end and terminated at the other, illuminated by a pulsed plane wave. In previous publication (Heyman, Friedlander and Felsen, Proc. IEEE, 77, 780-787, 1989) the *global* resonances, obtained by fully coupled interior and exterior have been compared with the partial resonances generated by individual uncoupled modes. The latter were found to describe adequately only the high-Q global resonances which are clustered near individual mode cutoff, indicating that these resonances are generated essentially by a *single* mode that undergoes a resonance phenomenon due to the weak radiation or coupling losses near cutoff. It is shown here that the late time observable carry the signature of these resonances in terms of a slowly decaying *typical* waveform, which is independent of the incident observation angle or of the excitation pulse. We also explore the earlier field which consists of the following consecutive contributions: 1) Direct interactions of the incident field with the scatterer (the so called intrinsic entire function); 2) A rapidly decaying series of external wavefront interactions (removable entire function); 3) First return of the wavefront that propagate down the waveguide cavity. By properly selecting the incident pulse shape and the incident/observation angle, one may de-emphasize these contributions and enhance the relative magnitude of the late time typical waveform.

Tuesday PM

URSI-A Session 48

RCS and Near Field Measurements

Chairs: Jonathan D. Young, The Ohio State University; Paul G. Ingerson, TRW - Antenna Systems Lab.

Room: W-115 *Time*: 1:15-4:40

RAPID NEAR-FIELD MEASUREMENTS OF ANTENNAS, RADOMES, AND TARGETS BY MEANS OF THE MODULATED SCATTERING TECHNIQUE

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The Modulated Scattering Technique (MST) employs arrays of electrically-small modulated scattering elements (crossed dipoles or slots) to rapidly map near-field (NF) electric fields radiated by antennas or scattered from targets [1, 2]. This paper summarizes the status of the MST array technology (1) for NF testing of antennas with and without radomes and (2) for NF measurements to determine radar cross section of complex scattering targets.

Numerical and experimental results obtained via 2nd and 3rd-generation MST prototype systems developed at Georgia Tech in the U.S. and at SUPELEC in France will be presented and discussed. Applications of MST technology to the development of fixed-site measurement facilities as well as portable measurement systems that can be transported to field sites will be included.

1. J. Ch. Bolomey, B. J. Cown, G. Fine, *et. al.* "Rapid Near-field Antenna Testing Via Arrays of Modulated Scattering Probes," IEEE Trans. Ant. and Prop., Vol. 36, June 1988.

2. B. J. Cown and C. E. Ryan, Jr., "Near-Field Scattering Measurements for Determining RCS," IEEE Trans. Ant. and Prop., Vol. 37, May 1989.

APPLICATIONS OF NEAR-FIELD TECHNIQUES TO THE DETERMINATION OF BISTATIC RCS AND TARGET SCATTERING CHARACTERISTICS FOR FUZE ENCOUNTER SIMULATIONS

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Near field techniques have been used for a long time to determine antenna patterns. Application of these techniques to scattering problems shows that they can also be used to determine both far field, polarimetric, bistatic RCS patterns and the field information needed for fuze encounter simulations.

The near field technique is a practicable method under consideration for determining the general, bistatic RCS of a full scale target. It would allow the entire measurement to take place in an enclosed space, thus permitting an all weather, secure facility to be developed for such measurements.

The near field technique allows the scattering properties of the target to be determined in a manner independent of the transmit/receive antenna pattern(s). This allows the receiver voltage to be determined along any encounter path for any known fuze antenna of the same frequency without the need of further measurements.

Experiments performed at Georgia Institute of Technology for the Air Force have demonstrated for scale models that Bistatic RCS and field data for fuzing can be determined from near field measurements. In this talk, methods will be proposed that would enable the development of capabilities to model full scale targets. Sampling issues and frequency diversity requirements that limit the technique will also be discussed.

THE EFFECT OF ANTENNA RADIATION PATTERN ON NEAR-FIELD RADAR CROSS SECTION

J.A.G. Malherbe, C.W.I. Pistorius* and K. Cloete
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Especially at millimeterwave-frequencies, the proximity of the observer to the target can cause large phase variations in the illumination of the target. This variation can be large enough so that the far-field RCS information becomes inaccurate. If the observer furthermore is in such close proximity to the target that the angle subtended by the target at the observer is larger than the beamwidth of the observer antenna, severe deviations from far-field properties are observed.

In this paper, the RCS of a target, in this case a flat plate, is calculated from the ratio of incident to reflected field strength by applying a numerical physical optics integration over the surface of the target. The current distribution is assumed constant over the surface of the target, and due to the close proximity between target and observer, the inverse distance and phase laws in the integral cannot be approximated. The near field RCS is evaluated both as a function of distance and of angle.

For high-gain antennas, the target is not illuminated in its entirety, and the nature of the backscattered field changes once again. The effect that the radiation pattern of the transmit-receive antenna has on the RCS is predicted theoretically, and verified by measurement.

NEAR FIELD DATA PROCESSING ON A 386 PERSONAL COMPUTER

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The development and implementation of near-field scanning devices has provided a practical and accurate method of measuring large antennas designed to operate at microwave and millimeter wave frequencies. Measurements of this type usually dictate a very large data grid to adequately characterize the far field. Data analysis techniques require computers capable of handling sizable data sets in an accurate and timely manner.

Until recently, analysis of large arrays was not practical on a desktop computer. Many personal computers were confined by the operating systems to 640K RAM which limits the data array size to approximately 144 X 144 data points. The advent of personal computers, employing the 80386 processor and DOS extenders using compatible Fortran compilers, have removed these limitations. A 25 Mhz, 386 PC with a math coprocessor and as much as 20 Mbytes of memory provides an efficient computer for near field data processing. The 386 Fortran 77 compilers have increased execution speed by 200-400% compared to the 8086/80286 systems, with an accuracy equal to a mainframe. This is over and above speed increases attributed to clock speed. The programs are portable and can address all available computer memory.

The planar near-field analysis programs developed and used at the National Institute of Standards and Technology have recently been converted to run on a 386 PC system. The pros and cons of 386 PC data processing will be discussed, including such factors as memory requirements, disk storage requirements, execution times and available graphical output.

EVALUATION OF COMPACT RANGES BY FIELD PROBING

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Microwave imaging techniques are widely used to identify the scattering centers associated with complex structures. One can also use these techniques to determine the locations and relative strength of the various scattering centers associated with an antenna's far field pattern (amplitude and phase). Recently, these techniques have also been used to evaluate compact range measurement systems, except that in this case the probed data is taken in the near field of the reflector. Thus, one should be careful in applying microwave imaging techniques to compact range problems in that the probed field data should be taken with sufficient degree of freedom to locate the scattering centers in three dimensional space. In this case, the amount of computation may make the imaging unattractive. Also, the probed fields contain a specular reflection term, which can not be directly imaged because the reflection point moves with the probe location. To avoid these problems, as proposed in this paper, for a given probe location, one should probe the fields at different frequencies and the imaging should be done in the time domain. In this case, one will not obtain the location of the scattering centers directly. However, since the compact range geometry is known, one can map the time delay to obtain the location of the various scattering centers. An advantage of probing the fields in the frequency domain is that one can use super resolution algorithms to resolve scattering centers with small separations. These ideas will be illustrated during the presentation.

PLANE WAVE ANALYSIS AND EVALUATION OF AN INDOOR FAR FIELD CONDUCTIVE CHAMBER

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Martin Marietta has designed and operationalized an indoor far field chamber used for radar cross section (RCS) evaluation. The 40'x40'x70' range has conductive walls on all sides except for the pyramidal absorber covered back wall. The conductive walls allow for the use of ray tracing for the determination of stray scattering signals in the quiet zone. Signal paths were traced until they reach the absorber lined back wall where they were considered terminated. The objective of this effort was to analyze and evaluate the plane wave quality in the chamber test region.

This paper will present an analysis of the conductive chamber using Geometrical Optics (GO). Optimal feed horn gain and beamwidth were investigated to achieve maximum quiet zone size and purity. The chamber was designed to have wall/floor/ceiling interactions occur with a distance (time) delay allowing for these signals to be isolated from the test region. Hardware and software gating techniques were used to remove the unwanted signals. Gating effects were combined with the GO analysis to further define the quiet zone.

Measured results of the quiet zone size and purity were compared to analytical results. The plan wave evaluation was performed using the angle transform technique. This relatively new technique involved measuring the complex RCS vs. aspect angle of a rotating cylinder. The component plane wave information was integrated in the angle domain and transformed to the spatial domain. The measured results validated the analytical results and generated a final determination of the quiet zone.

GEOMETRIC SCALE MODEL OF AN ANTENNA RANGE

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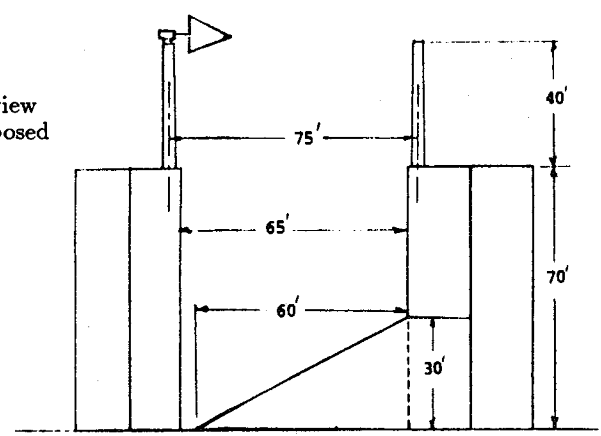
The purpose of building and testing a geometric scale model of a proposed outdoor antenna test range was to aid design validation. The scale model is a cost effective means of estimating the range's electrical characteristics and provides experimental control over the measurements.

A sketch of the proposed range is shown in Figure 1. The scale model was one-fifteenth size of the proposed range. The operational frequency band of the proposed range was from 0.05 to 0.70 GHz, which corresponds to a band of 0.75 to 10.5 GHz for the scale model. Frequency scans were measured with a HP8510B ANA and transformed to time domain data using a FFT. Time domain data exihibits range reflections according to the time delays associated with signal path length.

The initial objectives of the scale model investigation were to determine if there was any scattering off the range towers, measure the ability of a ground ramp to reduce inherent ground reflections, and identify any relationship between tower top deck scattering and mast position. The metal towers did not demonstrate significant scattering into the receive antennas. The ground reflection was clearly visible without the ground ramp. The addition of the ground ramp reduced ground reflections to less than -35 dB (referenced to the main signal) for all test cases. Significant scattering from the top deck was observed when the mast was moved toward the middle of the top deck.

The scale model investigation yielded two key results; the ground ramp performed acceptably and the amount of top deck scattering depends on mast position.

Figure 1. Side view sketch of the proposed antenna range.



FEED HORN WITH SUPPRESSED SIDELOBE LEVEL

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A horn antenna with suppressed sidelobe levels will be described in this paper. The backlobes of the horn are suppressed by curving the edges in the aperture of the antenna, as shown in Figure 1 below, making the horn a candidate for a compact range feed.

The Geometrical Theory of Diffraction (GTD) has been successfully applied to calculate the radiated fields from horn antennas. Knowledge of the GTD reveals that the radius and centre of curvature of an edge has a significant influence on the magnitude and behavior of the diffracted field. The authors postulated that curving the edges of the horn will change the sidelobe levels, especially in the back direction. A GTD analysis of the E-plane radiation pattern of the horn antenna was performed and compared with that of a similar horn with straight edges. This analysis indicated that the curvature of the edges does indeed modify the sidelobe levels and that the horn with the curved edges has significantly lower sidelobes in the region 90° to 180° (with 0° indicating boresight).

Two similar horn antennas were subsequently constructed, one with curved edges and the other with straight edges for control purposes. The radiation patterns for both horns were measured. These measurements confirmed the notion that curving the edges results in reduced sidelobe levels in certain sectors of the radiation pattern.

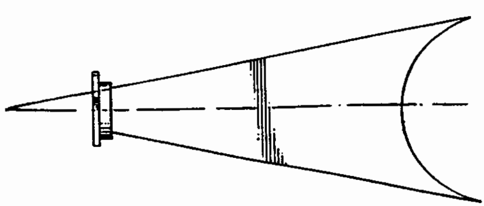

Figure 1.

DESIGN OF INFLATABLE TARGET SUPPORT FOR RCS MEASUREMENTS

By
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An inflatable stressed-skin structure can be used as a target support for radar cross section (RCS) measurements from VHF to millimeter-wave frequencies. A column is constructed of low-dielectric-constant, high-tensile-strength thin material, either plastic film or fabric. A foam plug is used to seal the top of the column and acts as a stiffening ring to rigidize the structure. The support is ideally suited for VHF measurements because of its low RCS. It is useful for millimeter-wave measurements because of its high stability. An optimization strategy has been implemented whereby a column can be designed to support targets up to 2000 lb at a height of 20 ft. Greater weights and heights are eminently possible. The optimization maximizes mechanical safety and stability and minimizes electromagnetic backscatter. Mechanical performance is determined by skin material properties, column dimensions, and target mass. Runout at the top of the column can be easily controlled within 1 mm. RCS performance is determined by summing the scattering from skin material, foam plug, and tape seams. The taper angle of the column can be set to provide minimum backscatter to the illuminating beam (spherical or plane wave). This design methodology is carried through for a 20-ft column designed to support 1000 lb with an RCS less than -40 dBsm at VHF frequencies.

Tuesday PM
Joint AP-S, URSI-B Session 49
Electromagnetic Analysis

Chairs: R. F. Harrington, Syracuse University; W. A. Davis, Virginia Polytechnic Inst. & State Univ.

Room: W-104 *Time*: 1:15-5:00

1:20	**Wideband FDTD Scattering from Dispersive Targets** Raymond Luebbers*, D. Steich, F. Hunsberger, K. Kunz, The Pennnsylvania State University; V. Cable, Lockheed Aeronautical Systems Company	AP-S
1:40	**Application of Time-Domain Finite-Volume Method to Antenna and Array Problems** A. H. Mohammadian*, V. Shankar, W. F. Hall, Rockwell International Science Center	AP-S
2:00	**Removal of Spurious Solutions in Finite Element Vector Boundary-Value Problems** Keith D. Paulsen*, Daniel R. Lynch, Dartmouth College	AP-S
2:20	**Determining Resonant Properties of Arbitrarily Shaped Planar Antennas** Ke Wu*, Ruediger Vahldieck, University of Victoria	AP-S
2:40	**Results of a Numerical Solution to the Lossy Waveguide Problem** W. A. Davis, S. E. Bucca*, Virginia Polytechnic Inst. & State Univ.	AP-S
3:00	**Coffee Break**	
3:20	**Input Admittance of Finite Length Insulated Linear Antenna** S. A. Saoudy*, Memorial University of Newfoundland; B. P. Sinha, University of Newfoundland	254
3:40	**Characteristic of the Scattering Field from a Lossy Medium Coated Conducting Sphere** Zhang Liyang, Wang Wenbing, Rugui Yang*, Xi'an Jiaotong University	AP-S
4:00	**Calculation of Bistatic Radar Cross Section from Polyhedron Structures by Using Modified Equivalent Current Method** Yonehiko Sunahara, Hiroshi Aoki*, Masato Inoue, Nobutake Orime, Seiji Mano, Takashi Katagi, Mitsubishi Electric Corporation	AP-S
4:20	**A Modified Strip Representation of a Flat Plate for a Plane Wave Diffraction Analysis** Makoto Ando*, H. Yoneda, Tokyo Institute of Technology; T. Kinoshita, Tokyo Institute of Polytechnics	AP-S
4:40	**Electromagnetic Penetration Through a Round Hole in an Infinitely Perfectly Conducting Slab** Jianwen Wei, Rugui Yang*, Xi'an Jiaotong University	AP-S

INPUT ADMITTANCE OF FINITE LENGTH INSULATED LINEAR ANTENNA

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and
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A Wiener-Hopf type analysis is employed to solve the problem of a dielectric-coated dipole antenna in both free space as well as a relatively dense medium. The analysis is done in general for a perfectly conducting dipole antenna coated by a low loss dielectric and embedded in either free space or a lossy medium with the latter's wave number larger than that of the lossy coating. Analytic expressions are derived for the input admittance and the current distribution along a center-fed antenna excited across a gap of non-zero width. Such expressions are presented in terms of a function representing the aperture gap field which is considered equal to that at the gap of a similar solid insulated antenna with infinite extension. For free space, results are in very good agreement with reported experimental results at different outer radii and dielectric constants of the dielectric coating for different antenna length. As for lossy medium, results obtained are compared with available literature data for different antenna length embedded in ambient medium with different loss tangents ($\sigma/\omega\varepsilon$). The numerical work involves only the determination of certain integrals using standard integration routines.

Tuesday PM
Joint AP-S, URSI-B Session 50
Polarimetric Bistatic Inverse Problem

Chairs: Sujeet K. Chaudhuri, University of Waterloo; Shi-Ming Liu, N. W. Polytechnic University

Room: W-110 *Time*: 1:15-4:40

1:20	**Polarization Correction of the Bistatic Formulation of P.O. Backscattering from Conducting Smooth Surfaces** Bing-Yuen Foo*, De Paul University; Wolfgang-M Boerner, The University of Illinois at Chicago	256
1:40	**Bistatic Microwave Diversity Imagery** Tah-Hsiung Chu*, Ding-Bing Lin, National Taiwan University	AP-S
2:00	**Bistatic Polarimetric Radar Target Imaging** Sujeet K. Chaudhuri*, University of Waterloo; Wolfgang-M Boerner, The University of Illinois at Chicago	257
2:20	**On the use of the Gradient to Determine Bistatic SAR Resolution** Gerard P. Cardillo*, Toyon Research Corporation	AP-S
2:40	**Multistatic Impulse Radar Reconstructing for the Arbitrary Incident Polarization Direction** Ma Xincai*, Feng Kongyu, Institute of Electronics Academia Sinica	AP-S
3:00	**Coffee Break**	
3:20	**Experimental Results from the CSM Tunnel Detection Facility Using EM Line Current Scattering (ELCS)** Robert J. Wayland, David O. Lee, Sandia National Laboratories; Steven M. Shope*, Sandia Research Associates, Inc.; Kenneth Zonge, Zonge Engineering & Res. Organization	AP-S
3:40	**Borehole Radar Measurements** Motoyuki Sato*, Tohoku University	AP-S
4:00	**Inverse Scattering for Dielectric Spheres** Jiang Li*, University of Houston; Weigan Lin, University of Electronics Science and	AP-S
4:20	**Variation Spectrum of Scattering Field** Hai Xu, Rugui Yang*, Xi'an Jiaotong University	AP-S

POLARIZATION CORRECTION OF THE BISTATIC FORMULATION OF P.O. BACKSCATTERING FROM CONDUCTING SMOOTH SURFACES

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and

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Bistatic scattering of a plane electromagnetic wave from a perfectly conducting, smooth and closed convex scatterer is considered under the physical optics assumption. Using Kennaugh's ramp response formulation of the monostatic case, Kennaugh's identity is extended to the bistatic case. In addition, Bennett's polarization correction to physical optics is applied and extended to obtain the polarization corrected elements for coherent scattering matrix expressed in the linear (H,V) polarization bases for the case in which the principal curvatures and the torsion terms at the specular points become appreciable. The obtained results are verified using monostatic and bistatic measurement data collected with the Ohio State University, Electro-Science Laboratory, In-Door Measurement Range.

BISTATIC POLARIMETRIC RADAR TARGET IMAGING

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The objective of this paper is to develop a model for target imaging in a multi-static environment using the complete broadband multi-static scattering matrix target phenomenology.

Electromagnetic scattering from a complex object, at high frequencies, is dominated by certain specular components. The location of these specular points on the complex object are known as the scattering centers. Generation of these scattering centers is dependent on the geometry of the object and its surroundings with respect to the aspect directions of the transmitters and receivers. It is shown that the knowledge of the locations, and the local geometries of these scattering centers are useful in developing target imaging models and multi-path target identification/discrimination algorithms.

Wednesday PM

Joint AP-S, URSI-B Session 51

Numerical Methods - Hybrid Techniques

Chairs: Steven Castillo, New Mexico State University; T. Cwik, Jet Propulsion Laboratory

Room: W-107 *Time*: 1:15-4:40

A FEM/BEM FORMULATION FOR A CG-FFT SOLUTION OF 2-D SCATTERING BY GROOVES AND THICK SLOTS

Jian-Ming Jin and John L. Volakis*

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This presentation deals with the electromagnetic characterization of the scattering properties of a groove or slot in a thick conducting plane filled with an inhomogeneous composite material. In particular, the computation of the scattering is considered for both transverse magnetic (TM) and transverse electric (TE) polarization. Of particular interest in this analysis is the introduction of a new technique that combines the finite element method (FEM) and boundary integral formulation. To allow the treatment of large grooves or slots, the conjugate gradient method (CGM) and fast Fourier transform (FFT) are employed for the solution of the resulting system. Numerical examples are presented that demonstrate the validity, versatility and capability of the technique.

The proposed numerical technique employs the FEM to formulate the fields within the groove or slot and establish a relationship with those at the aperture. The fields external to the groove or slot are expressed as an integral over the aperture which is discretized using the boundary element method (BEM). A system of equations is then obtained by enforcing field continuity across the aperture. This is solved via the CGM and in the process the boundary integrals are efficiently evaluated via the FFT.

Three notable advantages of the new technique are:

(i) as a result of using the FEM the cross section of the groove or slot can be arbitrary

(ii) for the same reason the material filling can be inhomogeneous and composite, and

(iii) inherently, the application of the CG-FFT results in a memory demand of $O(N)$, where N denotes the number of unknowns.

SCATTERING FROM 2D FINITE AND SEMI-INFINITE DIELECTRIC SLABS INCLUDING END EFFECTS

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For some time there has been interest in determining the electromagnetic scattering of dielectric slabs. Traditional moment-method codes that may be used for this purpose are accurate but are limited to low-frequencies and to slabs of narrow width. To overcome this difficulty, several authors have developed high-frequency techniques to determine the scattering from thin dielectric slabs. However, these latter methods do not include the complete scattering effects of the slab's ends. In this talk, a hybrid moment-method code is described that predicts 2D scattering of an E- or H-plane-polarized plane-wave from a finite or semi-infinite dielectric slab. End effects that may be produced by tapering the slab or by varying its dielectric constant are explicitly incorporated.

ELECTROMAGNETIC SCATTERING BY THICK STRIP GRATINGS EMBEDDED IN AN INHOMOGENEOUS MATERIAL

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The scattering of electromagnetic waves by a strip grating has been studied using a number of methods. A limitation of many of these methods is that they assume the strips to be infinitesimally thin. This may not be practical or even desirable. Furthermore, the material profiles are limited to being either homogeneous or piecewise homogeneous. In this paper, the problem of scattering by a grating consisting of thick strips embedded in a material with a spatially variant profile is considered (Figure 1). The solution is derived by using a hybrid technique that combines the finite element method and the method of moments. The two methods are coupled together by matching the tangential electric and magnetic fields across a fictitious closed surface *S* that encloses the unit cell.

The hybrid method is formulated in an efficient manner such that the finite element solution is treated independently, preserving its sparse properties. Finite elements are used to model the electromagnetic fields in the region enclosed by *S*, which is assumed to be highly inhomogeneous. The finite element solution is computed and the tangential fields, computed on *S*, are weighted by unknown coefficients and matched to the exterior region. In the exterior region, the fields are represented by an integral equation, with the periodicity accounted for with the use of the periodic Green's function. The unknown coefficients are then solved for using the method of moments.

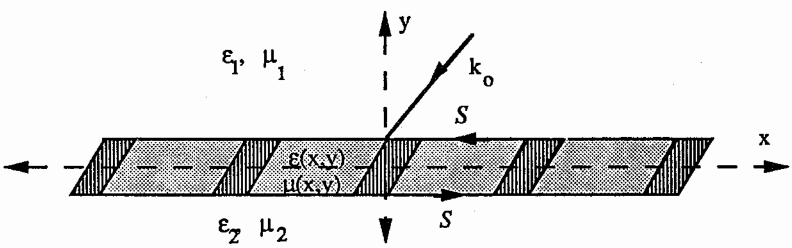

Figure 1. Example of a thick strip grating embedded in an inhomogeneous medium.

A Combined Boundary Element-Finite Element Formulation for Solution of Three-Dimensional Scattering Problems via Conjugate Gradient Fast Fourier Transform Method

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The numerical solution of scattering by electrically large three-dimensional bodies demands an *O(N)* storage requirement. The finite element method, which results in a sparse banded matrix, ensures this, but use of the boundary integral as an additional boundary constraint produces a full matrix, which may destroy the *O(N)* storage requirement. In this paper a method is proposed which maintains the *O(N)* storage requirement when employing a formulation based on the finite element method.

The Boundary Element - Finite Element CGFFT method (BE-CGFFT) combines the boundary element method with the finite element method (K.L Wu, G.Y. Delisle, D.G. Fang, and M. Lecours, IEEE Trans. Microwave Theory Tech., vol. MTT-37, pp. 993-998, Jun. 1989.) The proposed application of this method involves tightly enclosing the scattering body in a circular boundary. Within this boundary the usual finite element method is employed and the boundary condition on the surface of the cylinder is provided by imposing the Statton-Chu integral equation via the boundary element technique. Since some of the integrals are convolutions, they can be computed via the fast Fourier transform (FFT) and the resulting system may be solved iteratively via the CGFFT algorithm, thereby eliminating a need to generate and store a full matrix.

The principle advantage of the method is the *O(N)* storage requirement. The integrals which are not convolutions, however, must be evaluated from an interpolation table to guarantee *O(N)* storage at an obvious additional reduction in computational efficiency.

PROPAGATION AND SCATTERING OF EM WAVES IN ELECTRICALLY LARGE DUCTS

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The modeling and analysis of electrically large ducts with complex terminations is a problem of great current interst in radar cross section (RCS) studies. This paper describes a computationally efficient hybrid technique for analyzing such geometries. The propagation of electromagnetic waves in the duct is analyzed in terms of an approximate modal solution. The interaction between the propagating EM field and the complex termination is computed via a finite difference algorithm. A key technical challenge in such a hybrid approach is the development and the implementation of the boundary conditions that connect the modal solution to the finite - difference solution. Alternative formulations will be critically examined and numerical results will be presented for 2-D geometries.

HYBRID THIN–SLOT ALGORITHM FOR THE ANALYSIS OF NARROW APERTURES IN FINITE–DIFFERENCE CALCULATIONS

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It is well known that apertures that are narrow with respect to the spatial cell size present problems in time–domain finite–difference (FDTD) codes. Gilbert and Holland (*IEEE Trans. Nucl. Sci.*, 28, 6, 1981) suggested an algorithm to address this problem that required modification of certain field equations within the basic FDTD code. Taflove, *et al.* (*IEEE Trans. AP*, 36, 2, 1988), presented a simplification of the Gilbert–Holland algorithm and applied it to two–dimensional geometries. These are general– purpose algorithms that have been shown to be quite accurate, but the accuracy of the aperture field is a function of where E–field evaluation points are placed within the aperture (Turner and Bacon, *IEEE Trans. EMC*, 30, 4, 1988).

In this paper, a new technique for the FDTD analysis of narrow apertures with depth is proposed. This technique incorporates an independent "time–marching" solution for the aperture problem into the FDTD code. The equation that is solved is similar to the Pocklington linear–antenna equation. The solution is used as a magnetic current element in appropriate curl–E equations in the FDTD code. The inclusion of depth is possible by using an equivalent antenna radius recently derived for deep slots (Warne and Chen, *IEEE Trans. AP*, 37, 7, 1989).

One may argue that solving the Pocklington equation is appropriate provided one will be satisfied with an aperture distribution associated with half–space radiation. However, by judiciously using the FDTD code for field predictions local to the aperture, it is possible to create a feedback technique that includes all interior and exterior coupling to the aperture. This is useful, because it permits one to incorporate "half–space" integral–equation formulations into FDTD codes, without requiring specific Green's functions to be known.

The feedback scheme is realized simply by noting that the fields local to the aperture are composed of an outgoing wave generated at the present time step, plus a scattered wave due to magnetic current sources at earlier time. The specific form of the outgoing wave is known from the half–space solution; thus, by subtracting this term from the *total* field predicted by the FDTD code, evaluated at the same spatial position, one obtains a short–circuit field due to reradiation by any objects behind the aperture. The short–circuit term is included as an additional external source when the aperture distribution is computed from the Pocklington equation at the next time step.

To implement the scheme one only needs to: (1) keep track of the internal and external total H–fields local to the desired aperture position, and (2) append a magnetic current element to the appropriate H–field equations at each time step. The hybrid scheme gives rise to a "one–step" solution process.

Rectangular cavities which are loaded with boxes and wires have been successfully analyzed using this technique and will be discussed in detail.

A COUPLED FINITE ELEMENT—BOUNDARY INTEGRAL METHOD FOR ELECTROMAGNETIC SCATTERING PROBLEMS

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A coupled approach, combining finite elements in inhomogeneous portions of the scatterer with the boundary integral equation in homogeneous portions of the scatterer and in free space, has been formulated for electromagnetic scattering problems. This method attempts an exact solution of the problem, with dimensionality reduction by one in the homogeneous domain, but at the price of somewhat more complicated matrix structures than the sparse and banded matrices resulting from finite elements augmented by approximate absorbing boundary conditions.

The cases of homogeneous dielectric cylinders and coated conductors were tested by the boundary integral method. Very high accuracies, exceeding 10^{-3} dB at all scattering angles, were obtained for cylindrical geometries when compared with known analytic results for ka values varying from 1 to 10, using the simplest scheme of linear basis functions and point collocation. Results are also presented for rectangular and more complicated geometries, for which no analytic results are available.

The coupled approach has been implemented for the 2D case, as a preliminary step toward implementing a parallel 3D formulation on the JPL Mark III Hypercube. Test cases for the coupled model are, again, cylindrical dielectric cylinders and coated conductors. The method is fully applicable to more complex structures, such as ducts of various shapes, dielectric slabs with metallic strips attached to them, and so forth. The consistency, though not necessarily correctness, of the numerical calculations is verified by implementing the optical theorem (resulting from unitarity or energy conservation principles) in the RCS calculations.

The advantages and drawbacks of the coupled finite element—boundary integral method will be discussed on the basis of the numerical results obtained, as well as on the basis of computational requirements in terms of speed and memory.

ACCURACY OF THE FINITE ELEMENT METHOD FOR SOLVING OPEN-REGION SCATTERING PROBLEMS

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The accuracy of the moment method has applied to integral equation formulations of scattering problems has been studied extensively. Various parameters such as the type and number of basis functions affect the solution. Recently, the use of finite elements and finite differences for solving the wave equations directly has received considerable attention in the literature. These methods have several qualities which make them attractive for solving large problems. However, the accuracy of the solution is affected by a set of parameters not entirely related to factors affecting the accuracy of integral equation solutions. An understanding of the factors affecting numerical differential equation solutions is needed to increase the usefullness of these technqiues.

The finite element solution accuracy of open-region scattering problems are affected by sampling density, basis function order, and outer boundary placement. The sampling required to calculate a correct solution is based on the complexity of the fields that are excited by the scattering object. Factors such as the material and size of the object affect the spatial frequency spectrum of the solution that must be resolved by the numerical solution. The position at which the absorbing boundary condition must be applied for an accurate solution is similarly affected by the spatial frequency spectrum excited by the scatterer. Higher order basis functions can be used to resolve complex fields with fewer elements at the expense of computational complexity and some loss of matrix sparsity.

In this paper the affect of sampling density, basis function order, and outer boundary placement on the accuracy of the solution are examined. Both the TM and TE 2-D scattering problems are examined. Various canonical problems are studied as well as some non-seperable problems of sizes ranging on the order of three wavelengths up to thirty or more wavelengths. Comparisons are made to semi-analytical solutions for the seperable problems and to integral equation solutions for non-seperable problems. Some guidelines are given for boundary placement and sampling density for various types and sizes of scattering problems.

Wednesday PM
Joint AP-S, URSI-B Session 54
Active Element Arrays & Array Topics

Chairs: Phillip Richardson, Texas Instruments Incorporated; R. M. Sorbello, COMSAT Laboratories

Room: W-117 *Time*: 1:15-5:00

1:20	**Calibration and Test of an Active Conformal Phased Array** Jerome D. Hanfling*, Oscar J. Bedigian, Raytheon Company	AP-S
1:40	**A 4x4 Active Array Using Gunn Diodes** R. A. York*, R. C. Compton, Cornell University	AP-S
2:00	**32 GHz Power-Combining TSA Array with Limited Sector Scanning** J. Chang, D. H. Schaubert, K. S. Yngvesson*, University of Massachusetts at Amherst; J. Huang, V. Jamnejad, D. Rascoe, L. Riley, Jet Propulsion Laboratory	AP-S
2:20	**Design Study of an Integrated Array Architecture** John Litva*, Jian Wang, Russ Fralich, McMaster University	AP-S
2:40	**Measurement/Prediction Comparison for Ku-Band MMIC Active Phased Array for Satellite Communications** A. I. Zaghloul*, R. C. Mott, J. R. Potukuchi, R. M. Sorbello, F. T. Assal, H. B. Williams, COMSAT Laboratories	AP-S
3:00	**Coffee Break**	
3:20	**A Phase Scanned AEW Radar Antenna** R. Lagerlof, L. Josefsson*, Ericsson Radar Electronics AB	AP-S
3:40	**Phase Centre Movement in Linear Phased Array Antennas** A. Helaly*, A. Sebak, L. Shafai, The University of Manitoba	AP-S
4:00	**Planar Array Antenna** Alessandro Cucci, Francesco Madia*, Alberto Tomassoni, SELINIA S.p.A.	AP-S
4:20	**A 100-Element MESFET Grid Oscillator** Robert M. Weikle, II*, Zoya B. Popovic, Moonil Kim, Kent A. Potter, David B. Rutledge, California Institute of Technology	AP-S
4:40	**Optical Control of GaAs MESFET by an Illuminated Gap in Gate Metallisation** Peter R. Herczfeld*, Asher Madjar, Drexel University; Arthur Paollela, US ARMY, LABCOM	270

OPTICAL CONTROL OF GaAs MESFET BY AN ILLUMINATED GAP IN GATE METALLISATION

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+US ARMY, LABCOM, Electronics Tech. & Devices lab., Ft. Monmouth, NJ 07703

In recent years , interest in the optical control of microwave devices and circuits, particularly MMICs, has grown. In this paper a novel approach to the optical control of MESFET is presented. Previous schemes involved the illumination of the long and narrow active region of the device between the large metalic electrodes, resulting in poor optical coupling efficiency (1-2%). A typical microwave MESFET is usualy made up of several gate fingers connected to a common gate pad to which the external gate voltage is applied. In the proposed new method a photoconductive GaAs gap is created in the metallic line connecting the gate fingers to the gate pad by selective removal of the metalization, thus open circuiting the gate. Illumination of the gap enables control of the drain current by changing the effective gate resistance. This method provides very effective optical control.

Typical MESFET reverse gate currents range in the nanoamps, so to effectively "shorten" the gap by light very little optical intensity is neccessary (a gap resistance of several megohms acts like a short, since the voltage accross it is several tens of millivolts). The larger the resistivity of the substrate the better is the optical efficiency. The optimal case is a square narrow gap, which enables effective absorption of about 80% of the optical power (assuming a cylindrical light spot). For lower resistivity substrates the length/width ratio of the gap must be larger than 1 to increase the dark gate resistance (effective open-circuit). This reduces the optical efficiency to about 10% for aspect ratio 10:1. In the paper theoretical and experimental results are presented.

Wednesday PM

URSI-B Session 56

Complex Boundary Value and Half Space Problems

Chairs: T. B. A. Senior, The University of Michigan; D. G. Dudley, The University of Arizona

Room: W-102 *Time*: 1:15-5:00

ELECTROMAGNETIC RESPONSE OF A TRI-AXIALLY ANISOTROPIC HALF SPACE MODEL

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Electrical conduction in composite materials is not isotropic. Such is also the case in sedimentary rocks and other naturally occurring conductors. In dealing with such problems, it is usually assumed that the complex resistivity tensor is a uni-axially tensor with two elements the same. However, there are many situations where the three elements are different. We describe a method for dealing with a problem of this kind where we adopt a half-space model where the principal axis of the tensor is perpendicular to the planar interface. An exact solution for the boundary value problem, as stated, is outlined for the case where the sources are in the upper dielectric isotropic half-space. In particular we deal with a vertical magnetic dipole or small current carrying loop. It is shown that the radiation field of the loop in the upper half space is elliptically polarized in general. A similar method has been used in dealing with scattering from anisotropic cylinders(J.R. Wait, Electromagnetic Wave Theory, pg.185,Harper & Row/Wiley, 1984, where additional references are given).

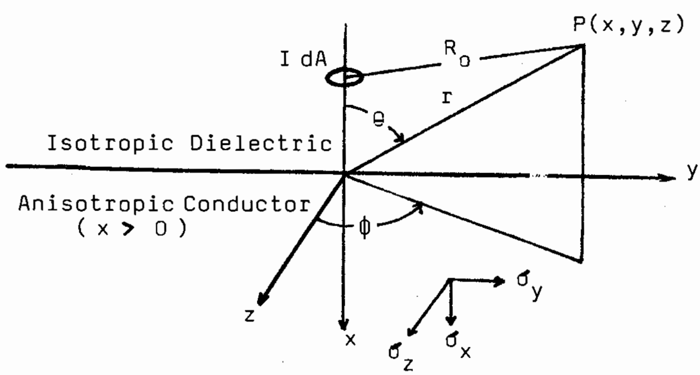

Fig. 1 Geometry for the anisotropic half space where the elements of the complex conductivity(or resistivity) tensor are different.

A PRELIMINARY INVESTIGATION INTO THE EXTENSION OF LS-DECOMPOSITION TO ACCOUNT FOR A CONDUCTING HALF-SPACE

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The procedure referred to as LS-decomposition has been shown to be an effective method for efficiently computing the elements of the impedance matrix when antenna structures are evaluated using moment method techniques (Simpson, Logan, and Rockway, URSI Abstracts, 356, June, 1988). In addition, antenna terminal impedance is easily obtained as a byproduct of LS-decomposition. In LS-decomposition the impedance matrix is expressed as

$$[Z] = j\omega[L] + \frac{1}{j\omega}[S] + \omega^2[Z_r] \quad (1)$$

where $[L]$ is an inductance matrix, $[S]$ is an elastance matrix, and $[Z_r]$ is the residual matrix. The inductance and elastance matrices are real and independent of frequency, and in the quasi-static limit the residual matrix is a real, frequency independent matrix.

In this paper the extension of LS-decompostion to take into account the effect of an infinite conducting half-space will be examined. This extension will allow the efficient evaluation of antenna structures operating in the proximity of the earth and the sea at low frequencies. In this preliminary study, a vertical dipole above a conducting half-space will be considered. For this case, the quasi-static Green's function is

$$G(\vec{r}|\vec{r}') \approx \frac{1}{4\pi}\left(\frac{e^{-j\beta R_1}}{R_1} + \frac{e^{-j\beta R_2}}{R_2} - j2\omega\epsilon_0\frac{1}{\sigma R_2}\right) \quad (2)$$

where $R_{\frac{1}{2}} = \sqrt{(x-x')^2 + (y-y')^2 + (z \mp d)^2}$, d is the source point elevation, $\beta = \omega\sqrt{\mu_0\epsilon_0}$, and σ is the conductivity of the conducting half-space. This approximate Green's function is exact in the limit as $\omega \to 0$.

Numerical results are obtained over a band of frequencies and compared to results obtained with Monteath's Compensation Theorem.

Half Plane Diffraction In Anisotropic Media

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Here we present an exact solution to the two dimensional diffraction problem of a plane wave incident on a perfectly conducting half plane which is embedded in a homogeneous ansitropic region. For $\hat{z}$ the axis parallel to the edge of the half plane, the medium is characterized by the following translationally invariant anisotropy:

$$\bar{\bar{\epsilon}} = \begin{pmatrix} \epsilon_{xx} & \epsilon_{xy} & 0 \\ \epsilon_{yx} & \epsilon_{yy} & 0 \\ 0 & 0 & \epsilon_{zz} \end{pmatrix}; \quad \bar{\bar{\mu}} = \begin{pmatrix} \mu_{xx} & \mu_{xy} & 0 \\ \mu_{yx} & \mu_{yy} & 0 \\ 0 & 0 & \mu_{zz} \end{pmatrix}.$$

Both electric and magnetic polarizations are considered. The solution has been obtained via mapping the anisotropic space into an isotropic region (with appropriate boundary conditions on the half plane) and employing a Sommerfeld-type integral representation.

ELECTROMAGNETIC SCATTERING BY CONDUCTING SPHEROIDAL OBJECTS WITH DIELECTRIC OR MAGNETIC COATING

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The scattering of electromagnetic wave by spheroidal objects has wide-ranging applications in areas such as attenuation of electromagnetic waves by rain drops, scattering by aircraft and missiles and biomedical effects of electromagnetics. The purpose of this paper is to present an analytical solution for the problem of electromagnetic scattering from conducting spheroidal objects coated with lossy/lossless dielectric or magnetic material for a plane wave excitation. The analysis is based on the eigenfunction technique, where the fields are expanded in terms of spheroidal wave functions in the coating and exterior regions with unknown expansion coefficients which are then determined by applying proper boundary conditions on the conducting surface and on the interface between the coating and free space. This technique has been used to extend the formulation for a perfectly conducting spheroid (B. P. Sinha and R. H. MacPhie, Electromagnetic scattering by prolate spheroids for plane waves with arbitrary polarization and angle of incidence, Radio Sci., vol. 12, pp. 171-184, 1980) to the present coated case. The solution investigated here can be extended to homogeneous coated spheroids and applied, as limiting cases, to treat coated dipole and disc antennas.

The numerical result has been checked using two approaches: (i) by setting the relative permittivity and permeability of the coating to unity, thus reducing to the perfectly conducting spheroid and yielding results identical to the published results of Sinha and MacPhie, (ii) by changing the axial ratios of the spheroid and coating to unity and reducing to a coated sphere. Quantitative results of the scattered far-field for different spheroid core and coating sizes will be presented to illustrate the effect of coating material, particularly on the scattering cross-section.

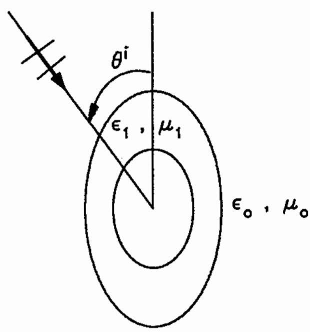

Fig. 1: Scattering geometry of a conducting spheroid coated with a dielectric.

On the Use of Generalized Impedance Boundary Conditions

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Higher order boundary conditions are now being used to simulate material effects in scattering, but when they are applied to edged structures such as a wedge or half plane, several complications arise. Whereas for boundary conditions of order zero and one (i.e. less than the order of the wave equation) self-adjointness automatically ensures a solution which satisfies the reciprocity condition, higher order conditions do not in general lead to a self-adjoint problem and, hence, to a reciprocal solution. Reciprocity must therefore be enforced explicitly. The boundary conditions in conjunction with the usual edge condition allow this to be done, but then the solution is not unique unless additional constraints are imposed.

To illustrate these problems, second order boundary conditions are introduced and discussed, and subsequently applied to a half plane illuminated by a plane wave. In order to justify the application of the Wiener-Hopf technique, it is necessary to consider the tangential integral(s) of the fields. The resulting solution, though not inherently reciprocal, contains a sufficient degree of arbitrariness for reciprocity to be imposed, and a unique solution satisfying the edge condition then contains a single arbitrary constant. It is shown that the constant is related to the surface values of certain field components at the edge, and the specification of this information, derived from a consideration of the actual structure being modelled, is necessary for a unique solution. The generalization to higher order boundary conditions is also discussed, and for Nth order conditions the solution contains N-1 arbitrary constants which can be related to the surface values of N-1 field quantities at the edge.

WAVE PROPAGATION IN MEDIUM WITH CYLINDRICAL AND HORIZONTAL DISCONTINUITIES

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Axially symmetrical wave generated by electrical dipole or electric current loop satisfies the following vector wave equation (assuming exp(-iωt) time dependence)

$$p \nabla \times \frac{1}{p} \times \mathbf{A} - \omega^2 \mu\varepsilon \mathbf{A} = i\omega p \mathbf{J} \qquad (1)$$

where

$p=\varepsilon$, $\mathbf{A}=\mathbf{H}$, $\mathbf{J}=\mathbf{J}_m$ for electric dipole

$p=\mu$, $\mathbf{A}=\mathbf{E}$, $\mathbf{J}=\mathbf{J}_e$ for electric current loop

and μ and ε are functions of r when cylindrical discontinuities exist. **J** has only a φ-component, consequently **A** in Eq.(1) contains only φ-component also. We can find eigenfunctions which are the homogeneous solutions to the above equation, that is

$$[\, \rho\, p \frac{\partial}{\partial\rho} \frac{1}{\rho p} \frac{\partial}{\partial\rho} + \frac{\partial^2}{\partial z^2} + \omega^2 \mu\varepsilon \,]\, A_\varphi = 0 \qquad (2)$$

Assume that

$$\rho A_\varphi = \sum_n f_n(\rho)\,[\, \exp(-ik_{nz} z)\, a_n + \exp(ik_{nz} z)\, b_n \,] \qquad (3)$$

where a_n and b_n are constants independent of r and z. Also, let $f_n(r)$ be expressed by a set of basis functions

$$f_n(\rho) = \sum_m b_{nm}\, g_m(\rho) \qquad (4)$$

substituting Eq. (4) & (3) into (2) yields the eigenvalue k_{nz} and eigenvector $\mathbf{b}_n$ for each of the horizontal layers. Then, with the help of layer propagator $P_L(z_1,z_2)$, which propagates the wave from one position to another within a layer, and connection matrix P_B, which relates the wave of two adjacent layers, we can get the coefficient a_n and b_n.

The method has a very clear physical meaning, requires comparatively less comnputing time and is very useful in well-logging applications. This method is used to solve the problem of a measurement-while-drilling resistivity sonde in a layered earth formation.

ELECTROMAGNETIC WAVE SCATTERING FROM FRACTAL SURFACES

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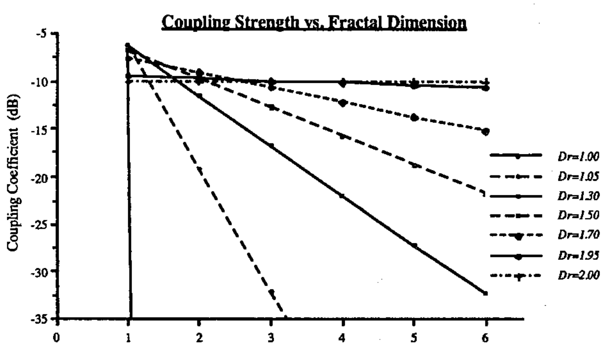
Wave interaction with rough surfaces has been of research interest for several decades. Here we use fractal functions, instead of the traditionally used simple periodic or random functions, to model rough surfaces. These bandlimited multi-scaled fractal functions blend periodicity and random feature. They more accurately describe naturally occurring rough surfaces and provide an explicit representation amenable to calculation.

It is physically intuitive that each harmonic in the rough surface will couple the incident plane wave to a different scattering direction. Here we formulate the strength for each combination of couplings by generalizing the Rayleigh method. This generalization applies to almost periodic structures. Of particular interest in this work is electromagnetic wave scattering from fractally corrugated surfaces, a special self-similar subset of almost periodic functions.

We calculate the scattering coefficients from conducting fractal surfaces through truncating a linear system and examine their convergence properties. We find, among many interesting results, that the slope of the scattering coefficients for different couplings as a function of normalized spatial frequency K is characteristic of the fractal dimension of the rough surface, as demonstrated in the figure below.



The first-order coupling coefficients of harmonics for different fractal dimension D_r are plotted in a log-log scale as a function of normalized spatial frequency K. The slopes of the coupling coefficients are strongly and monotonically dependent on the fractal dimension D_r.

HOW END EFFECTS ALTER THE BACKSCATTER PATTERN FOR A BODY OF CONSTANT SECTION

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When end effects can be neglected, the backscatter radar cross section (RCS) for a constant section body of length L has the general form

$$\sigma = \sigma_{ENV} \sin^2 (kL \sin \theta),$$

with k the wave number and θ the obliquity angle, that is, the angle which the line of sight makes with a plane normal to the axis of the body. The shape of the backscatter pattern is controlled by the envelope function σ_{ENV}, which is independent of L. The location of the pattern nulls depends only on kL.

This paper shows how the general form of the pattern changes when simple end effects, those corresponding to rays directly diffracted at the two ends, are included in the analysis. Specifically, the general RCS equation becomes

$$\sigma = \sigma_{BASE} + [\bar{\sigma}_{ENV} - \sigma_{BASE}] \sin^2 (kL \sin \theta + \tau).$$

Here $\bar{\sigma}_{ENV}$ is the new envelope function, also independent of L. But now the pattern also has a minimum envelope, a lower bound or *base value* independent of L given by the function σ_{BASE}. Furthermore, the position of the new relative nulls, the values of θ at which

$$\sigma = \sigma_{BASE},$$

is controlled not just by kL but also by the phase shift angle τ, which is independent of L but does in general depend on θ.

This paper also shows how the basic pattern characteristics are related to the diffraction coefficients for scattering per unit length and for endpoint scattering.

SPLINE MODELLING TO COMPUTE THE RCS OF ARBITRARILY SHAPED CAVITIES BY THE GO/AI METHOD.

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The presence of cavities is of great importance for the RCS of global structures. When the cavities are of various wavelength, the computation of the RCS can be done by the GO/AT method [H. Ling, R.C. Chou, S.W. Lee. "Shooting and bouncing rays: Calculating the RCS of an arbitrarily shaped cavity". IEEE TAP, Feb 89, pp 194-205.] Spline modelling is the most versatile form to handle arbitrary geometries.

To get confidence with the programs that implement the GO/AT method it was solved the case of open-ended waveguide cavities which appear in the literature. Then, some kind of spline polynomials were used to model arbitrary geometries: the NURBS (Non-Uniform Rational B-Splines). Each point on the surface can be obtained by a parametric function given by a set of nodes, control points and weights.

This parametric representation of the surface makes more complicate the ray tracing.One problem is finding the point on the surface of the cavity where one ray is going to bounce. This is similar to the problem which is solved in image generating when trying to simulate the effect of light [K. I. Joy, M.N. Bhetanabhotla. "Ray tracing Parametric surface patches utilising numerical techniques and ray coherence". Proc. of SIGGRAPH'86,1986,pp 279-285.]. Once the reflection point is computed, the normal and the second derivatives in that point are needed to obtain the direction of the reflected ray and its radii of curvature.

Sometimes only one spline allows to represent the whole surface. If it is not possible, to avoid problems in the boundary between contiguous splines, it is necessary to guarantee the continuity of the second derivative of the spline. This makes the spline to be of order three or greater.

Some examples of geometries will be presented with the results of RCS.

RAPIDLY CONVERGENT ALGORITHM OF THE INVERSION OF SCHWARZ-CHRISTOFFEL CONFORMAL TRANSFORMATION

Qian Jian, (Dept. of Inform. Phys., Nanjing University)

Abstract- Schwarz-Christoffel conformal transformation (SC mapping) is one of the most powerful tool for seeking the solution of two-dementional problems in electrostatics, magnetostatics, heat flow, hydrodynamics, elasticity and other fields. It can map the upper half plane into the region enclosed by a polygon, and the inversion of SC mapping then can map the interior of a polygon onto the upper half plane. In most cases, the inversion of SC mapping is more complicated and can not be performed analytically. Many authors have made great effort to search numerical techniques for it (E.Costamagna, IEEE Trans. Microwave Theory tech., Vol. MTT-35, 1, 35-40,1987). In this paper, important improvements are proposed which may guarantee the iteration to be rapidly convergent. Briefly, here are the main points.

1) A reasonable objective function is constructed aimed at to reduce a variable, that is the square sum of relative errors of side-length ratio of the polygon. It is of benefit to optimization procedure.

2) Not need to select the original value for iteration. At the beginnig, a set of "side-length" on real axis correcponding to the polygon can be determined arbitrarily without affecting convergence.

3) A convergence critirion of objective function is established, which is used as a threshold. Above this threshold a relaxation method is applied, and as soon as the objective function is lower down under it, relaxation continued but remain neccessary data for several iteration periods and then turn to a recurrence secant approch method. It will converge rapidly.

4) An divergence-against program is applied, which can prevent divergence automatically for special cases.

5) Appropriate variable exchange can remove the singularities and speed the numerical integral.

A unified program has been editted as described above, which can map arbitrary polygon onto the upper half plane with very high speed. For example, we can obtain a significant figure of 16 for a general microstrip line problem with total iteration number of 10.

Wednesday PM

Joint MTT-S, AP-S, URSI Special Session 57

Time Domain Analysis of Planar Circuits

Chairs: R. Mittra, University of Illinois; Wolfgang J. R. Hoefer, University of Ottawa

Room: W-105 *Time*: 1:15-5:00

1:20*	**TLM Modeling of Planar Guiding Structures** Wolfgang J. R. Hoefer*, University of Ottawa	284
2:00*	**Three-Dimensional TLM Method for Planar Radiating Structures** A. Papiernik*, D. Pompei, O. Benevello, Universite de Nice-Sophia Antipolis	285
2:40*	**Treatment of Dispersive and Anisotropic Properties of Substrate Mediums by Spatial Network Method** Norinobu Yoshida*, Ichiro Fukai, Hokkaido University	286
3:20	**Coffee Break**	
3:40*	**A Comparative Study of Maxwell's Equation Solvers in the Time-Domain** R. Mittra*, S. Kosanovich, Paul Aoyagi, University of Illinois; R. Gieger, Motorola Incorporated	287
4:20*	**General Discussion** R. Mittra*, University of Illinois; Wolfgang J. R. Hoefer, University of Ottawa	

TLM MODELING OF PLANAR GUIDING STRUCTURES

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Considerable progress has been made during the 1980's in time domain modeling of microwave and millimeter wave structures using the Transmission Line Matrix (TLM) method of analysis. The principal driving forces have been the new challenges faced by designers: shrinking and more densely packed circuits, shorter impulses and faster transients in digital circuits, dispersion due to higher losses at mm wavelengths and to the inhomogeneity of multi-layered substrates, nonlinearities, and multiple field interaction between discontinuities, devices, and packaging, - to name only a few. On the other hand, computers have become so powerful that four-dimensional analyses of realistic structures can now be performed. User-friendly interfaces provide considerable freedom and versatility in complex field modeling.

After a brief tutorial introduction to Transmission Line Modeling in two- and three-dimensional space, a number of novel TLM concepts and procedures will be presented. They include the modeling of frequency dispersive boundaries in the time domain, in particular the simulation of non-TEM absorbing boundaries, using a time domain diakoptics approach. This procedure, first described by P.B. Johns in 1981, has been reformulated as a numerical Green's function approach, also called the "Johns Matrix" approach in honour of the late pioneer of the TLM method. It has opened unprecedented possibilities for large-scale numerical preprocessing of substructures, the partitioning of large time domain problems at the field level, and for combining other numerical techniques with the TLM method. Other new TLM procedures are the wideband modeling of matched impulsive sources, the wideband extraction of complex scattering parameters from a single impulsive TLM analysis of a n-port, and the time domain modeling of nonlinear devices and frequency dispersive materials.

Finally, several applications of these concepts to microwave and millimeter wave CAD will be demonstrated, and some thoughts on the future evolution of field theory based design methods will conclude the presentation

THREE-DIMENSIONAL TLM METHOD FOR PLANAR RADIATING STRUCTURES

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This paper presents the study of radiating structures, particularly microstrip antennas, using the transmission line matrix (TLM) method. This involves the consideration of specific problems related to the unbounded nature of the space studied.

Introduction of absorbent walls: To simulate unbounded space, it is necessary to introduce absorbent walls so that the TLM mesh extends over a limited domain. This involves loading TLM lines with an impedance at the boundaries of the simulation space identical to the wave impedance of the medium. The absorbent property of these walls is perfect under normal incidence, and highly satisfactory for an obliquely incident wave (SWR < 1.05 for an incident angle of less than 58°, over a frequency bandwidth of 35%).

Characterization of the antenna: The input impedance is deduced from the standing wave observed in the feedline. The radiation pattern is determined from the field over a plane located in the immediate vicinity of the antenna, using the theory of radiating apertures. The first investigations were carried out using a time domain Fourier transform to obtain the aperture field at the frequency selected, then a spatial Fourier transform to determine the far field radiation. This method consumed an excessive amount of memory space. If the object is to find the radiation in certain planes (E or H for example), computation time and memory space can be reduced significantly by determining the time-domain radiation, then using a time-domain Fourier transform, thus avoiding the space domain Fourier transform.

Filtering and linear prediction: If the radiating structure has several resonant frequencies, it is convenient to apply classical digital signal processing techniques such as finite impulse response filtering associated with a linear prediction method. In this case, overall CPU time is reduced by a factor of 2 to 3.

The paper discusses the results obtained for the impedance and radiation patterns. The structures studied were slot-fed multilayer microstrip antennas. This represents a new field of application for the TLM method, since the drawback of the latter have been removed by limiting the simulation space using absorbent walls, simplifying the computation of radiation patterns, and utilizing appropriate signal processing methods.

TREATMENT OF DISPERSIVE AND ANISOTROPIC PROPERTIES OF SUBSTRATE MEDIUMS BY SPATIAL NETWORK METHOD

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Hokkaido University, Sapporo 060 Japan

To examine precisely the characteristics of the planar integrated circuit, the considerations of dispersive and anisotropic properties of a dielectric substrate have become important, especially in the time domain for a pulse wave.
The Spatial Network Method, for a transient analysis of three-dimensional electromagnetic fields, is based on both the expression of Maxwell's equation by a three-dimensional lattice network and the formulation of the one-dimensional line between lattice points by the Bergeron's method in the time domain. Since the Bergeron method defines both voltage and current variables at each port of the line, each lattice points is treated as a node where the continuity law about currents occurs. This treatment realizes a iteratvely computed nodal equation at each node, including medium and boundary conditions expressed as lumped elements. The reactance elements are formulated by approximating their voltage-current characteristics by the trapezoidal rule in the time domin and directly included in the nodal equation.
For the computation of the dispersive characteristics, by applying the trapezoidal approximation, a iteratively computed differenc equation can be also performed. As an example, the following fundamental equation for the orientation polarization characteristics is considered.

$$\frac{dPu(t)}{dt}+\frac{Pu(t)}{\tau}=\frac{\varepsilon_0 \chi_e}{\tau}\,Eu(t) \qquad (1)$$

Here, Eu, Pu, τ, and χe are the electric field of the $u(=x, y, z)$ direction, the polarization, the relaxation time, and the relative polarization, respectively. The above equation can be transformed to the following difference equation by considering the relation between the displacement current Ic and the time variation of the polarization Pu; $Ic=dPu/dt$.

$$Vu(t)-RpIc(t)=-Vu(t-\Delta t)+RpIc(t-\Delta t)\ +2Pu(t-\Delta t)/\varepsilon_o \chi_e \qquad (2)$$

$$Rp=(\tau/\varepsilon_0 \chi_e+\Delta t/2\,\varepsilon_0 \chi_e)$$

Here, Rp corresponds to the characteristic resistance of the polarization in the time domain. Since all the terms on the right hand side of this equation are obtained only from the previous time step, this equation is iteratively computed.
On the other hand, the diffinition of currents at each node makes it possible to treat genarally an anisotropic medium. The off diagonal terms in the tensor permittivity of the dielectric substrate can be formulated by mutual connection between the bi-directional magnetic-currents at each nodes.
These treatments can be further extended to the gyro-anisotropic medium such as a ferrite which constructs the non-reciprocal devices for micro- and millimeter waves.

A COMPARATIVE STUDY OF MAXWELL'S EQUATION SOLVERS IN THE TIME-DOMAIN

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R. Geiger
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In this paper, we discuss the results of analytical and numerical studies of three different time-domain techniques for solving Maxwell's equations. These are: (i) the TLM method; (ii) the FDTD method; and, (iii) the Bergeron method. The formulations of these methods, which have been found useful for deriving solutions of both open and closed region problems, typically follow distinctly different paths. The TLM and Bergeron methods begin by using networks of transmission lines, gyrators (Bergeron method) and stubs to model the space, which may be inhomogeneous. The solution for the voltages and currents on the network, by using a time-stepping procedure, is then shown to be equivalent to constructing the solution of Maxwell's equations in the time domain. The two methods do differ, however, in the manner they construct the solution--The TLM method employs a scattering matrix formulation to generate a solution in terms of voltages (equivalently plane waves) in a discrete region of space, and the fields are obtained from a combination of the scattered voltages (plane waves). The Bergeron method obtains a solution in terms of six variables directly related to the electric and magnetic fields at the nodes. In contrast the FDTD method deals directly with Maxwell's equations in differential form, and solves for the field quantities on the Yee-lattice rather than using voltages and currents on transmission lines as an intermediary step. The FDTD, Bergeron and the original version of the TLM method all employ staggered nodes for E and H fields; however, the TLM condensed node version locates all six field quantities at a single spatial point.

In this paper, we show how the TLM and Bergeron formulations can be related directly to the discretized Maxwell's equations, without the use of transmission lines. We examine these discretized equations from the point of view of numerical stability, and show that only certain forms of these versions are stable for extracting a time domain solution. We also compare the computational efficiency and accuracy of all three methods by solving some representative problems. Finally, on the basis of these studies, we draw some conclusions on the comparative merits of the three methods.

Wednesday PM1

Joint AP-S, URSI-B Session 58

Biomedical Applications

Chairs: Magdy F. Iskander, University of Utah; Stan J. Kubina, Concordia University

Room: W-106 *Time*: 1:15-3:00

1:20	**Microwave Hyperthermia Using Retro-Focusing** M. Dwayne Sawyer*, Martin Marietta Astronautics; Jochen Edrich, University of Colorado at Denver	AP-S
1:40	**An Asymmetric Intracavitary Applicator for Hyperthermia Treatment of Cancer** Charles W. Manry, Jr.*, S. L. Broschat, Washington State University; C.-K. Chou, K. H. Luk, J. A. McDougall, City of Hope National Medical Center	AP-S
2:00	**Finite Difference-Time Domain Analysis of Power Deposition Pattern of an Array of Interstitial Antennas** Paul Cherry, Magdy F. Iskander*, University of Utah	AP-S
2:20	**Thin Applicator Having Coaxial Ring Slots for Interstitial Microwave Hyperthermia** Koichi Ito*, Manabu Hyodo, Masaru Shimura, Haruo Kasai, Chiba University	AP-S
2:40	**Modelization of the Single and Double Coplanar Applicators for Biomedical Applications** J. Pribetich*, C. Seguinot, P. Kennis, P. Pribetich, Univ. Des Sciences ET Tech. De Lille	290

MODELIZATION OF THE SINGLE AND DOUBLE COPLANAR APPLICATORS FOR BIOMEDICAL APPLICATIONS.

J. PRIBETICH, C. SEGUINOT, P. KENNIS, P. PRIBETICH

CENTRE HYPERFRÉQUENCES & SEMICONDUCTEURS
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One of the main objectives of using microwaves in hyperthermia for cancer treatment is to develop the capability of delivring therapeutic heat to deep-seated tumors without overheating the surrounding healthy tissues. For these applications, coplanar applicators were found to provide superior performances as compared to the other kinds of radiating structures.In fact, these coplanar waveguides are very efficient to couple the electromagnetic energy in the medium under investigation. A recent paper [1] has pointed out the first step of such analysis of coupling characteristics of coplanar waveguides to multilayered lossy dielectric media. But, that study has focused only on the role and the influence of superstrate. In order to improve the efficiency of the coupling of the electromagnetic energy, we propose to investigate a new planar applicator: the double coplanar applicator (Figure 1) laid on the lossy material and covered or not with a superstrate.

Furthermore, we want to get more informations on the single coplanar applicator, that's to say the complex propagation constant and the associated characteristic impedance and, finally the distribution of the electromagnetic energy in the medium under investigation in order to compare the performances of the two structures. So, this study is devoted to the analysis of these two structures in order to obtain the fundamental characteristics (relative effective permittivity, attenuation and associated characteristic impedance). For this study, we use the wellknown Spectral Domain Approach (S.D.A.).method.

As example, we give on figure 2 the evolution versus frequency of the relative effective permittivity as a function of the ratio $k = w / (w + 2s)$.

At the Conference, in May, we will present the main steps of that numerical analysis in order to obtain the fundamental characteristics of the studied structures. In a design purpose, design chart will be presented showing the influence of the geometrical and physical parameters.

REFERENCES

[1] M.F. ISKANDER and T.S. LIND." *Electromagnetic coupling of microstrip lines and coplanar waveguides to multilayer lossy media*" . M.T.T.'s Symposium - Long Beach (13 -16 June 1989) pp 175-178.

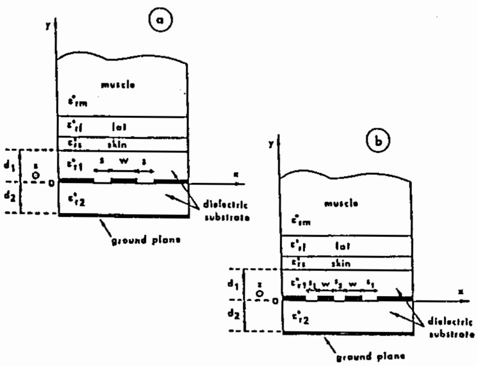

Figure1 : Schematic diagram of the studied structures
a - single coplanar applicator
b - double coplanar applicator

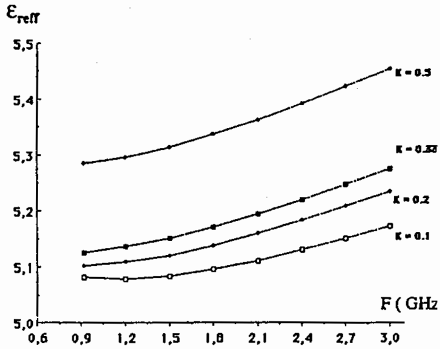

Figure 2 : Frequency behaviour of the relative effective permittivity ε_{reff} as a function of the ratio $k = w / (w + 2s)$

Wednesday PM2
Joint AP-S, URSI-B Session 59
RF Passive Components

Chairs: Bill Powers, Texas Instruments Incorporated; Allen Love, Rockwell International Corporation

Room: W-106 *Time*: 3:15-5:00

3:20 **A Novel Four-Way Power Divider Design Using TOUCHSTONE CAD Software** AP-S
Jian Wang*, Mike Spenuk, John Litva, McMaster University

3:40 **Spectral Domain Analysis of Electrically Wide Short-Circuit Discontinuities in Slotline** AP-S
James McLean*, Hao Ling, Tatsuo Itoh, The University of Texas at Austin

4:00 **Analysis of Printed Probe Loaded Ridged Waveguides** AP-S
Ruediger Vahldieck*, Ke Wu, University of Victoria

4:20 **Designing SECH Profile Optical Waveguides from Prescribed Characteristics** 292
Lakshman S. Tamil*, The University of Texas at Dallas; Duncan Mills, Unified Industries Inc.

4:40 **A Full-Wave Analysis of Waveguide T-Junction with an Inductive Post** AP-S
Jiro Hirokawa*, Kimio Sakurai, Makoto Ando, Naohisa Goto, Tokyo Institute of Technology

DESINGING *SECH*^{2} PROFILE OPTICAL WAVEGUIDES FROM PRESCRIBED CHARACTERISTICS

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Gradient-index optical waveguides are usually designed by iterative techniques based on the solution of the associated direct scattering problem. A refractive index profile, e.g., a parabolic or a constant profile, is assumed, and the propagation constants are calculated; then the assumed profile is modified, and the direct scattering calculations are repeated until the specified modal structure is obtained. In contrast, an inverse scattering theory prescribes the modal structure or propagation constants, and then the requisite refractive index profile is determined from this information.

We present here a procedure based on the inverse scattering theory to design single mode planar optical waveguides with *sech*^{2} refractive index profile. The wave equation for the electric field in the core is transformed into a Schrodinger-type equation whose potential function is related to the refractive index profile. The modal structure of the waveguide is characterized by the transverse reflection coefficient. The propagating mode is accounted by prescribing a reflection coefficient with a pole on the upper imaginary axis of the complex wave number plane and a pole in the lower imaginary axis accounts for the evanescent modes normally present in a practical waveguide. The Gel'fand-Levitan-Marchenko inverse scattering theory is used to obtain the unique solution of the potential function and hence the refractive index profile from a rational representation of the reflection coefficient. We also present confirmation of the inverse scattering results using direct scattering calculations.

Wednesday PM
URSI-B Session 62
Electromagnetic Radiation

Chairs: R. W. Ziolkowski, Lawrence Livermore National Laboratory; J. M. Putnam, McDonnell Douglas Research Laboratories

Room: W-104 *Time*: 1:15-5:00

MODELLING ELECTROMAGNETIC RADIATION FROM A CIRCUIT BOARD WITH COATED COVER AND SLOTTED SHIELD

Jean-Fu Kiang

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The radiation characteristics of microstrip antennas have been widely studied mainly for applications in communications. However, they are seldom considered in the printed circuit boards used in the frequency range from 30 MHz to 1 GHz. The understanding of radiation properties in this frequency range is necessary to have the design of circuit boards satisfy the FCC requirements.

A metallic coating on the plastic cover has been used to shield radiation from terminals to the neighboring equipment. The information about its effectiveness is important. We also analyze the leakage through ventilation slots on the shield.

In this paper, we apply a spectral domain formulation to microstrips radiating in a stratified medium. The substrate, plastic cover, and the metallic coating are all considered as layers of the stratified medium. The surface current on the microstrips are represented by a set of rooftop basis functions. The Galerkin's method is used to solve the integral equation for the current distribution. The radiation field is then obtained by using the stationary phase integration method.

Both the coupling effect among adjacent microstrips and the shielding effectiveness of metallic coating on the plastic cover are analyzed. It is found that the radiation around resonant frequencies are critical to satisfy the FCC requirement, and an appropriate coating can resolve the problem.

The radiation through slots is analyzed by first formulating two equivalent problems corresponding to two sides of the metallic shield. Then, the same procedure is applied to solve the magnetic current distribution on the slots from which the radiation leakage can be obtained.

ANALYSIS OF ANTENNAS WITH ARBITRARY APERTURES

J. M. Putnam* and L. N. Medgyesi-Mitschang

A surface integral equation based formulation is described for analyzing cavity-backed aperture antennas. The apertures are assumed to be planar but of arbitrary shape embedded in an infinite conducting ground plane. The analysis is specialized for arbitrary rotationally symmetric configured cavities. The method of moments technique is used to solve the integral equations of the problem. To achieve computational efficiency, two different expansion sets are used to span the cavity and aperture surfaces, specialized to take advantage of surface geometry. The Galerkin procedure additionally leads to symmetry relationships in the system matrix. Using the foregoing formulation, a variety of irregular apertures will be examined as it impacts the antenna gain and input impedances. Published results for antennas with linear and circular slots will be used for comparison of the present formulation. Detailed descriptions of the near fields in the neighborhood of these antennas will also be investigated.

ANALYSIS OF ANTENNA CHARACTERISTICS AT OUT-OF-BAND FREQUENCIES

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The radiation properties, including gain patterns and impedance mismatches, of antennas at out-of-band frequencies are computed by the moment method. The out-of-band properties are essential to the solution of electromagnetic coupling between systems, such as EMC (electromagnetic compatibility) and EMP (electromagnetic pulse) problems.

The antennas analyzed are low gain antennas, such as the glide-slope loop antenna. As can be envisioned, the radiation pattern is easier to compute than the impedance mismatch because the former is stationary with respect to the current distribution on the antenna. Our computational results show that even for the more difficult impedance data, the agreements with measured results are sufficiently good for EMC and EMP applications.

For example, the glide-slope antenna made by Dorne and Margolin which operates between 329 and 335.3 MHz, is an effective bandpass filter with high mismatch loss at out-of-band frequencies. Computation between 50 and 4,000 MHz clearly shows this property and agrees well with measured data.

Difficulties in out-of-band analysis are primarily in the modelling of the impedance network. The structures of the antennas were revealed by X-ray films. The antenna geometry, including the matching network, is then modelled and computed.

Gaussian Beam Algorithm for Transmission of EM Fields from a Two-Dimensional Plane Aperture through a Rotationally Symmetric Shaped Radome

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and

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Abstract

In a sequence of recent publications by the authors, it has been shown that the fields radiated from a one-dimensional plane aperture distribution through planar and cylindrical dielectric layers can be accurately calculated by narrow-waisted Gaussian beams distributed on a self-consistent configuration-wavenumber phase space lattice. It has been argued that the algorithm, being rigorously based and stabilizing for different lattice arrangements, yields results with a priori predictability when each of the Gaussian basis beams is propagated through the environment by complex ray tracing. It was also found that a few paraxially approximated beams suffice to predict the null shift (boresight error, BSE) produced by the layers when the aperture field possesses a central null. These results for two-dimensional test configurations are now generalized to three dimensions. A two-dimensional vector aperture field distribution is assumed to be surrounded by a rotationally symmetric ogive-shaped dielectric radome. The aperture field is decomposed into Gaussian vector basis elements distributed self-consistently over a two-dimensional phase space lattice. A three-dimensional complex ray tracing algorithm has been constructed to propagate the narrow-waisted vector beams produced in this manner through the radome, due account being taken of the polarization in this process. Stabilization of the beam algorithm onto independently generated reference solutions in free space has been verified first on several numerical examples. A few relevant beams have then been traced paraxially through the radome to determine the BSE in the principal plane of an E-polarized aperture. The results are shown to be consistent with those for limiting spherical and cylindrical layer shapes. As in the two-dimensional case, the paraxial Gaussian beam algorithm furnishes a reliable and efficient method for three-dimensional BSE prediction.

MULTIPLE COUPLED CONCENTRIC OPEN AND CLOSED RING MICROSTRIP ANTENNAS

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The resonance frequencies of multiple coupled concentric open and closed ring microstrip antennas are computed. The spectral domain technique is used to compute the charge distribution of the coupled rings and the corresponding quasi-static capacitances. The current profile is defined in terms of the charge distribution and the inductances of the coupled rings are evaluated. The capacitances and inductances are used in an equivalent circuit model of the rings to determine the resonance frequencies.

The mathematical formulation for the capacitances of the coupled rings is similar to the one adopted for the microstrip disk [T.Itoh and R. Mittra, MTT-21, 431-432, June 1973]. The Hankel transform of order zero is introduced to solve Poisson's equation for the potential with specified boundary conditions. A number of different basis functions for charge distributions on the rings are used to compute the capacitances.

For the inductance calculation of the coupled rings, a solution is sought for Poisson's equation for the vector potential **A** with boundary conditions that are slightly different than those in the capacitance problem. This solution is obtained by using the Hankel transform of order one.

In this paper, the resonance frequencies are computed for a variety of multiple ring structures on typical microstrip antenna substrates. The quasi-static computation of self and mutual capacitances and inductances are shown and results are presented for rings with different radii, widths, and separations.

Localized Wave Transmission Physics & Engineering †

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Exact solutions of the scalar wave and Maxwell's equations that describe localized transmission of wave energy will be reviewed briefly. These acoustic and electromagnetic localized wave (LW) solutions can be optimized so that they are localized near the direction of propagation and their original amplitude is recovered out to extremely large distances from their initial location. Pulses with these very desirable localized transmission characteristics may have a number of potential applications in the areas of directed energy applications, secure communications, and remote sensing.

The underlying physics of the LW effect is closely connected to the additional degree of freedom obtained by coupling together the usually disjoint portions of phase space: position and frequency, by the nonseparable space-time nature of the LW solutions. The frequency spectra at different locations in the aperture are different but are highly correlated. A moving, localized interference pattern results in a pulse whose shape is reconstituted as it propagates by the frequency components arriving at different times from the various aperture sources.

If these LW solutions are used to drive an array of radiating elements, the engineering is different from conventional continuous wave (CW) excitations of that array. One does not simply incorporate a phase shift into a CW signal from one location in the array to a different one. The elements must be independently addressible. Different broadband pulses, hence, different frequency spectra, must be loaded into the array at specified locations to achieve this requisite spatial spectrum correleation behavior.

Simulations as well as recent experimental results for a 25 element, 1.0 cm square, acoustic array will be shown. They demonstrate a more than ten-fold improvement of the distance over which localization is maintained than is expected from conventional CW excitations of the same array. Simulations for an analogous microwave experiment will also be discussed.

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† This work was performed by the Lawrence Livermore National Laboratory under the auspices of the U. S. Department of Energy under contract No. W-7405-ENG-48.

EMP-Induced Currents in Wire Antenna Arrays

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The evaluation of EMP-induced currents in wire antenna arrays is described for both parasitic arrays (e.g., Yagi-Uda antennas) and arrays in which all elements are driven (driven arrays). The EMP-illuminated antenna is represented by the Norton equivalent circuit seen at the terminals of the antenna source. For the driven array, a simple model for the feed network is described and the relationship between the currents on the elements of the array and the current at the source terminals is made explicit. The relevant electromagnetic problems are solved in the temporal frequency domain by using the method of moments and the modified diakoptic theory (Schwering, et al., *IEEE Trans. Antennas Propagat.*, AP-34(11), pp. 1273-1280.) Time-domain short-circuit currents and currents excited in a load impedance replacing the array source are calculated for a range of excitations.

OPTICAL INTERACTIONS WITH THE HUMAN RETINAL ROD: A COMPUTATIONAL ELECTROMAGNETICS MODEL

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In this paper, we report the first investigations of visible light interactions with the human retina based upon detailed computational electromagnetics modeling. Specifically, we concentrate on the rod receptor cell of the retina. The computational electromagnetics approach for the rod is based upon the finite-difference time-domain (FD-TD) method utilizing a two-dimensional transverse magnetic (TM) model for the actual three-dimensional cell geometry.

In this research, the rod is modeled with a spatial resolution of 5.0 nm (5×10^{-9} m), equivalent to approximately $\lambda_o/100$ at the wavelength of green light (λ_o = 505 nm). The rod is comprised of disk membranes stacked one on top of the other like poker chips. Individual disks are 15 nm thick and 1,960 nm in diameter, separated from adjacent disks on each side by 10 nm of fluid. Overall dimensions of the disk membrane stack are 20,000 nm by 2,000 nm (approximately $40\lambda_o$ by $4\lambda_o$ at the wavelength of green light), with a 15 nm thick wall surrounding the entire stack. The entire rod is assumed to be immersed in fluid. To establish the sensitivity of the results to the assumed tissue properties, our studies vary the disk membrane index of refraction over the range 1.42 - 1.45 and the separation-fluid index of refraction over the range 1.35 - 1.37, corresponding to generally accepted physiological data ranges. The incident light is a plane TM-polarized wave directed along the rod's long axis (20,000 nm), and is permitted two complete front-back-front traversals of the rod to let the computed optical fields reach the sinusoidal steady state. This requires 2.4 hours of single-processor Cray-2 time.

We report detailed results for the induced optical standing wave fields within the retina rod model for three visible light wavelengths: red (700 nm); green (505 nm); and violet (400 nm). The data are reduced and analyzed to obtain values for both local and global-averaged optical electric fields and intensity. For comparison, we also report data for the rod model with the disk membrane stack replaced by a homogeneous bulk membrane.

COMPUTATIONAL MODELING OF ELECTROMAGNETIC HYPERTHERMIA: Three-Dimensional and Patient-Specific

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We have developed a semi-automated method for obtaining patient-specific electromagnetic (EM) hyperthermia models. Using computer vision technology, a patient's computed tomography (CT) scans are analyzed to reconstruct his 3-D tissue geometry. This tissue structure data base is then automatically translated via a software interface to the dielectric media data base of a finite-difference time-domain (FD-TD) numerical EM absorption model, resident on a Cray.

This paper will describe initial results of this procedure. We first provide validation of the FD-TD numerical model for free-space radiated fields from open-ended waveguides and horn antennas (via comparison with the method of moments). Then, we discuss 2-D and 3-D FD-TD models of EM hyperthermia of a human thigh due to a waveguide applicator, wherein the thigh data base is derived by analyzing a multiplicity of CT images of a patient.

The 3-D model of the human thigh (with 0.5 cm resolution) is reconstructed from 29 serial CT image slices using the elastic interpolation technique. The boundaries between the fat, muscle, bone, and bone marrow regions are obtained by thresholding the CT numbers and then applying automatic contour tracing methods. A dielectrically-loaded waveguide (with and without a quarter-wavelength matching layer) is applied to the human thigh data base. The effects of the dielectric loading of the waveguide applicator are shown in plots of the penetrating electric field and specific absorption rate (SAR) for both two and three dimensions, and the two and three dimensional results are compared.

NUMERICALLY-DERIVED ABSORBING BOUNDARY CONDITIONS FOR THE SOLUTION OF OPEN REGION SCATTERING PROBLEMS

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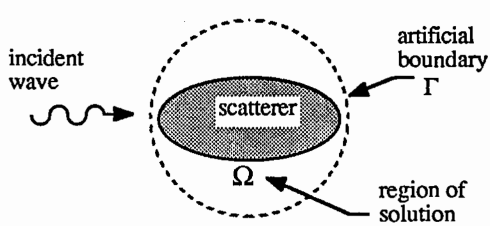
It has been recently demonstrated by Mittra and Ramahi (Differential Methods in Electromagnetic Scattering, Elsevier, 1989, Ch. 4) that the ABCs derived from asymptotic analysis, e.g., the Bayliss-Turkel and the Enguist-Majda operators, exhibit noticeable errors in the higher-order harmonic content of the scattered field when the outer boundary is brought very close to the scatterer to reduce the number of mesh points, even when higher order forms of ABCs are used. The purpose of this paper is to derive a more accurate ABC that attempts to circumvent the above problem by numerically approximating the exact analytical form of the boundary condition for a range of harmonic number n, which is determined by the size of the scatterer.

For a two-dimensional problem, the scattered field u can be represented at the artificial boundary as $u = \sum a_n H_n^{(2)}(k\rho)e^{jn\phi}$, where $H_n^{(2)}(k\rho)$ is the Hankel function of the second kind. It follows, then, that for each harmonic term in the series, the ratio u_ρ/u is given by $(\partial H_n^{(2)}(k\rho)/\partial\rho)/H_n^{(2)}(k\rho)$, which will be designated here as γ. For a given $k\rho$, we approximate γ over the desired range of n in terms of a polynomial in n^2 as $\gamma^{ap} = a_0 - a_1 n^2 + a_2 n^4 + ...$, and interpret n^2 as being equivalent to the angular operator $\partial^2/\partial\phi^2$. This leads us to a numerical ABC which reads

$$u_\rho = a_0 + a_1 u_{\phi\phi} + a_2 u_{\phi\phi\phi\phi} + ...$$

By using finite differencing at the outer boundary in conjunction with finite elements throughout the solution region, the higher order derivatives can be implemented without any significant decrease in the sparsity of the matrix system. Numerical results are presented in the paper that demonstrate the enhancement in the accuracy that can be achieved over the conventional, analytical type of ABCs by using the new numerical boundary condition.



Wednesday PM

Joint AP-S, URSI-B Session 63

Polarimetric Transient and Broadband Imaging

Chairs: Carl E. Baum, Weapons Laboratory/NTAAB; K. J. Langenberg, University of Kassel

Room: W-110 *Time*: 1:15-5:20

SEM AND EEM SCATTERING MATRICES, AND TIME-DOMAIN SCATTERER POLARIZATION IN THE SCATTERING RESIDUE MATRIX

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This paper extends the singularity expansion method (SEM) and related eigenmode expansion method (EEM) parameters from the currents on scatterers to the scattered far fields. The scattering matrix, when taken to the SEM poles, becomes a scattering residue matrix with special properties. For non-degenerate natural modes this 2 x 2 matrix is a single dyad with zero determinant. One of the vectors in the dyadic product represents the scatterer polarization (with respect to the observer) independent of the incident field. For the case of backscattering the scattering residue matrix is a symmetric dyad characterized by a 2-component vector (two complex numbers). This vector characterizes the polarization of the scattered field with respect to the observer. Considering the damped sinusoidal form of the poles in time domain, one can think of this as elliptical spiral polarization. In terms of the usual scalar coupling coefficients the normalized in-line backscattering coupling coefficient is just the square of the usual normalized coupling coefficient for the natural mode currents.

Symmetries in the scatterer induce other properties in the backscattering residue matrix. Rotation symmetry (C_∞) induces modal degeneracy (two fold). An axial symmetry plane makes the vectors characterizing the backscattering residue matrix perpendicular to or parallel to this plane. For on-axis illumination the presence of C_N symmetry for $N \geq 3$ makes the backscattering polarization parallel to the incident polarization.

PERFORMANCE ANALYSIS OF A NEWLY DEVELOPED RADAR TARGET DISCRIMINATION TECHNIQUE

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The performance of a radar target discrimination technique using multiple–frequency scattering amplitude without phase data is investigated in this study. The aspect–independent discrimination scheme in frequency–domain is based on the concept of natural resonance frequencies. The method utilizes the fact that most targets of interest reveal significant resonance phenomenon in the radar cross section (RCS). Assuming that a data base of natural frequencies for targets of interest is known *a priori*, this approach provides a real–time discrimination. An algorithm employing the FFT is also investigated to overcome the effect of noise for practical situations. The performance of the "FFT approach" is examined.

Instead of the Rayleigh and low resonance frequency ranges, the proposed algorithm can be applied in the higher frequency region. It is believed that only using dominant natural frequency is not sufficient to distinguish similar targets, and what is further needed may be the higher–order resonance which includes partially the detailed information about targets.

In the simulation, the radar cross sections (RCS) of spheroids are calculated numerically to model the received radar returns for distinguishing different spheroids and wires in the resonance frequency range. By Monte Carlo simulation, the discrimination error rate at different aspect–angles is estimated as a function of the standard deviation of added complex Gaussian noise. The numerical results show that the discrimination algorithm works well under moderately noisy situations and can be applied in high resonance frequency range though its performance depends on aspect–angle. The reason may be that the resonance strengh of the RCS depends on aspect–angle. That is, though the technique is based on the aspect–independent natural resonance frequencies, the intensity of each resonance does depend on aspect–angle.

THE 4 - SPHERE APPLICATION FOR REPRESENTATION AND ANALYSIS OF PARTIAL POLARIZED WAVES

L.A.Zhivotovsky; V.I. Ul'yanov (Lenin) LETI, USSR

It is shown in the paper that there is a possibility to introduce partial-polarized wave in the one point on a sphere. It was realized on the base of author method of multidimentional sphere visibility and modification of Stocks vector.

It is known that a Stoks vector module changes by change of polarization degree with invariable wave intensity. Therafore, it is difficult to use a classicad Stocks vector for analysis of partial-polarised waves.

The author proposes such a modification of Stocks vector that its module is invariable when polarization degree changes. It gives possibility to employ polarization 4 - sphere and to make a clear representation of partial-polarized waves.

It is shown that there is simplification of some polarization problems, for example problems to sum non-coherent waves and decomposition of wave at non-coherent composite. A correct distance between partial-polarized waves and between wave and antenna is defined in paper as a distance between correspondent points on 4 - sphere.

The polarization 4 - sphere method has turned be useful method has turned to be useful method not only for polarization problems, but also for analysis of 2 x 2 ehrmit matrix with any determinant.

Broadband Polarimetric Microwave Holography

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Based on a Huygens-type integral representation of the electromagnetic field scattered by perfectly conducting or dielectric obstacles a generalized vector holographic field is defined with the aid of the backpropagation principle. It can be related to the equivalent current sources induced on or inside the scatterer in terms of a vector integral equation of the Porter-Bojarski type. Under the assumption of broadband incident fields of arbitrary polarization, and provided, that either the Kirchhoff or the Born approximations hold for the scatterer, this integral equation can be inverted with regard to the currents for arbitrarily chosen measurement surfaces not necessarily in the far-field. In addition, an efficient numerical processing scheme, based on Fourier transforms only, is proposed for circular cylindrical measurement surfaces. Computer simulations are provided for the case of a spherical perfectly conducting scatterer.

SIMULTANEOUS INVERSION OF PERMITTIVITY AND CONDUCTIVITY PROFILES USING MONOCHROMATIC DATA OF HYBRID POLARIZATION

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A survey of the literature reveals that most of the existing monochromatic profile inversion methods utilize an iterative Born approach in the implementation of the reconstruction process. Moreover, the transverse-electric (TE) polarization is typically the only case discussed in the literature. This is because the approach does not work well at high frequencies or for the transverse-magnetic (TM) polarization, but appears to be useful only for the low frequency transverse-electric (TE) case. This is attributed to the fact that at high frequencies or in the case of the TM polarization, the inversion problem becomes highly nonlinear rendering perturbative approaches inappropriate.

In this paper we present an inversion algorithm based on a recently developed inversion method referred to as the Renormalized Source-Type Integral Equation approach (T.M. Habashy, E.Y. Chow., and D.G. Dudley, URSI meeting, Blacksburg, Virginia, June 15-19, 1987). There are a number of apparent advantages to this approach: i) it is an exact inversion equation; hence, if approximations are to be made they will occur in the numerical methods employed in the solution of this inversion equation, ii) it has an explicit dependence on the unknowns to be inverted for; hence, allows one to compute the derivatives of the response with respect to these unknowns in a closed form, iii) by pre-storing the elements of the inversion equation (which depend only on the background medium and are independent of the unknown profile), the method does not require the solution to the full forward problem repeatedly as in the case of the Distorted Born approach and is therefore significantly faster in implementation, and v) it allows, in some cases, the rigorous study of the degree of nonuniqueness involved in the inversion, a point of great importance in the design problem.

In this paper, the inversion scheme is demonstrated for the case where the exciting source is of the dipole type that generates waves of hybrid polarization (TE and TM polarized waves). The inversion will be tested for two types of data: the first employs the magnetic field components and the second employs the electric field components measured at various locations on the probed medium's surface performed at a number of frequencies.

Thursday AM
URSI-B Session 64
Numerical Methods - III

Chairs: J. J. H. Wang, Georgia Institute of Technology; Hao Ling, The University of Texas at Austin

Room: W-107 *Time*: 8:15-12:00

APPLICATION OF SCALAR PERIODIC GREEN'S FUNCTION TO NUMERICAL SOLUTION OF PLANAR PERIODIC STRUCTURES

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Electromagnetic problems which satisfy the planar periodicity conditions in source and geometry can be solved numerically by the moment method with the Floquet modes as the expansion functions. Conventionally this is done by mode matching at planar interfaces defined by z = constant. However, this method is inadequate in handling geometries that are complex (for example, having complex z-dependent geometric variations as in some modern phased arrays and frequency-selective surfaces).

It is well known that in free space as well as in canonical bounded regions, the Green's function method allows the formulation, and thus the numerical solution, of problems involving rather "arbitrary" shapes and geometry. It is demonstrated here that by using a scalar periodic Green's function, an integral equation can be formulated to incorporate 3-D arbitrary shapes in the unit cells.

The arbitrary shape of the structure, such as an element in an infinite planar array, is discretized into triangular patches. The use of Galerkin's method, in which the weighting functions are identical to the basis functions, circumvents the difficulties in source singularity whenever a z-directed current (or equivalent current) perpendicular to the plane of periodicity exists.

Numerical results are quite satisfactory and will be discussed in the presentation.

Scattering by an Aperture Formed by a Filled Cavity in a Ground Plane

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Two formulations are presented for computing the scattering by a three-dimensional material filled depression (crack) in an infinite ground plane (see Figure). One of the formulations involves the use of generalized impedance boundary conditions (GIBC) to construct a set of integral equations in terms of surface equivalent currents placed on the aperture of the cavity. This approach avoids an explicit computation of the cavity's Green's function and is therefore applicable for depressions of arbitrary cross section. More importantly, all integrals are convolutions and the resulting system can then be solved via the conjugate gradient FFT (CGFFT) method having an O(N) memory demand. However, a careful implementation of the GIBC is required near the periphery of the cavity whenever the conditions are abruptly terminated. A second formulation was also pursued for validation purposes. This is restricted to rectangular shape cavities and is based on a traditional approach making use of the modal Green's function. The resulting integral equations again involve the aperture equivalent currents and are implemented via the standard method of moments solution. Of interest in this case is the computation of the diagonal and near diagonal elements of the admittance matrix and the convergence of the mode summations.

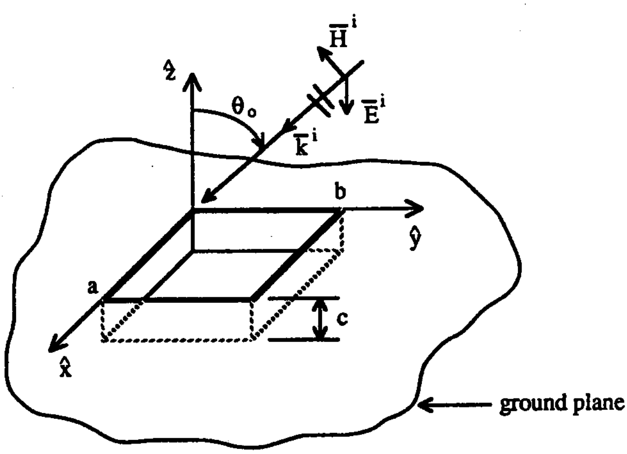

Fig. 1. Geometry of the cavity aperture in a ground plane.

SCATTERING FROM 3-DIMENSIONAL CRACKS USING IMPEDANCE BOUNDARY CONDITIONS

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This paper describes a numerical technique using impedance boundary conditions to compute the off-normal scattering from a narrow 3-D trough in a perfectly conducting ground plane, filled with dielectric/ferrite material. The local surface impedance at the opening of the trough is approximated by the dominant lowest order mode impedance looking into a 2-D parallel plate waveguide terminated by the short at the bottom of the trough at that point (T. Senior, J. Volakis, IEEE Trans AP-37, 6, 744-750, 1989). Integral equations for the tangential magnetic field in the aperture are solved by means of the equivalence principle, as the solution to the complementary problem of a complex resistive ribbon in free space with reversed polarizations. The numerical solution is obtained using OSU's ESP method of moments code with the appropriate resistivity varying as a function of local gap dimensions and material properties. The results are multiplied by 2 to account for the ground plane.

Predictions for an electrically shallow 10 wavelength long rectangular trough are compared with "exact" method of moments solutions and predictions obtained with other approximate methods. The high lobes associated with a travelling wave known to propagate down a deeper trough (A. Dominek et al., IEEE Trans AP-37, 5, 586-591, 1989) are not present. For shallow troughs this propagation mode is evanescent and does not contribute to backscatter. At exactly .25 wavelengths, the surface impedance at the opening is infinite and the solution is almost identical to that of a open slot in a ground plane. From Babinet's principle the solution is then identical to that of a perfectly conducting long thin ribbon whose large travelling wave lobes are well known.

The impedance boundary condition approximation for narrow 3-dimensional troughs significantly reduces computer computation time and may be used for arbitrary shapes and material filler. The approximation is less accurate for aspects very close to the axial direction.

ANALYSIS OF ARBITRARY SHAPED PATCH ANTENNAS UTILIZING TRIANGULAR PATCHES AND THE SOMMERFELD GREEN'S FUNCTION

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Abstract:

In this presentation, the triangular patch model is used for the analysis of radiation from arbitrary shaped microstrip structures situated over an infinite dielectric and a ground plane. So that the Sommerfeld Green's function is used in this technique. This formulation has the advantage over the volume/surface formulation and surface/surface formulation in the sense that this technique reduces the number of unknowns while increasing the computation time for the evaluation of the semi infinite integrals. Numerical results are presented for comparison with the surface/surface formulation and the volume/surface formulation. The results are quite accurate, however the disadvantage of this approach is that the signal level on the other side of the ground plane is always zero. So the backlobes cannot be computed with this approach. The versability of the trianglar patch modelling will be illustrated through numerical examples of radiation from triangular, circular and other different types of patch antennas.

STUDY OF THE RCS OF SOME RESONANT SIZE CONDUCTING BODIES USING THE METHOD OF MOMENTS: COMPARISON BETWEEN WIRE AND PATCH MODELING.

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Although some powerful numerical methods are recently appearing in the electromagnetic scene the Method of Moments (MM) is still a useful tool to solve some electromagnetic problems. The MM together with modeling techniques can provide one a great versatility in some applications involving bodies of resonant size.

The application of MM to calculate Radar Cross Section (RCS) is examined in a practical way studying the RCS of some conducting bodies of resonant size.

This study have been accomplished using two computer codes that correspond to two different modeling methods:

- The PDMPH2 computer code (J.L.F.Jambrina. JINA'86,pp.42-45. Nice Nov.1986) is based on MM and wire modeling.
- The PARCHES computer code, which is an adapted version of the code developed by M.F.Costa and R.F.H rrington (Eastern Research Lab.-D.E.C.). It is also based on the MM and the structures are modeled by triangular patches.

Criteria for the optimization of the wire and patch models will be presented. Some geometric tools have been developed in order to obtain the wire and patch models of the perfectly conducting structures to be analyzed: metallic disk, rectangular plate, cube, icoxahedron, etc.

The monostatic and bistatic RCS of these bodies have been calculated. A comparison between the results obtained using the two mentioned methods will be presented.

A LEAST SQUARES ANALYSIS OF INTER-ELEMENT COUPLING IN MICROSTRIP ARRAYS USING MOMENT METHODS

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Various techniques have been used to calculate the mutual coupling of microstrip antenna elements, the coupling of passive microwave circuit components in the feed network of the antenna, and the coupling between the radiating elements and the feed network [Mosig & Gardiol, Proc.IEE, H, 132, 1985],[Mosig, IEEE MTT-36 #2 1988],[Mohammadian, Martin, & Griffin, IEEE APS-37, #10, 1989]. These calculations are important since for a given microstrip antenna array an appreciable amount of inter-element coupling can result in an impedance mismatch with the feed network.

In this paper a procedure is introduced that will give a minimum square residual solution to a moment method formulation of the microstrip antenna array problem. Subdomain expansion and testing functions are prescribed, but more testing functions are used than expansion functions. The resulting system of equations is overdetermined and is solved using the Moore-Penrose inverse, which gives the least squares solution directly.[Chen & Gao, IEEE MTT-37 #10, 1989], [Frank & Balanis, IEEE GRS-27, #3, 1989], [Penrose, Proc. Cambridge Phil. Soc., 51].

$$J = (Z^T Z)^{-1} Z^T E^i$$

First, the procedure is applied to calculate the inter-element coupling of microstrip patches as a function of the proximity of the patches to one another. The changes in the current distributions and in the resulting far field patterns are computed. Next the coupling of a microstrip array with a nearby microstrip transmission line is calculated. The change in the radiated field of the array is computed as are the dispersion characteristics of the transmission line.

In conclusion it is shown that the least squares procedure provides an efficient way to compute the electromagnetic characteristics of microstrip antenna configurations of general shape.

RCS OF ARBITRARY FINITE CYLINDER WITH VARYING CROSS-SECTION

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WPAFB, Dayton, Ohio

Krishna Murthy Pasala
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In this paper we consider the problem of computing the scattered fields from a class of finite cylinders whose cross-section along the axis of the cylinder changes slowly. An approximate technique is devised to obtain the surface currents. This technique consists of approximating the current on the contour of a slice to be the same as that on an infinite cylinder with the same cross-section. Thus, determining the current on a three dimensional body is reduced to computing the current on a series of two dimensional problems. A target whose cross-section is changing smoothly is approximated by a target whose cross-section changes in stepped fashion. The target need not be perfectly conducting; it may be a dielectric body or partly or fully coated perfectly conducting body. The scattering from the real edges that are present at the top and bottom of the target are taken into account by the use of Ufimtsev's equivalent currents.

This theory was tested on an ogival frustum. Scattered fields were measured at 10 GHZ for both TE and TM polarizations and for back-scattering direction as well as bi-static directions. These measurements are compared to computations carried out and based on the theory described here. The surface currents as two dimensional cylinders are computed using the method of moments, sinusoidal Galerkin in the TE-case and Pulse Galerkin in the TM-case.

Finite Difference Analysis of Optical Fibers

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and
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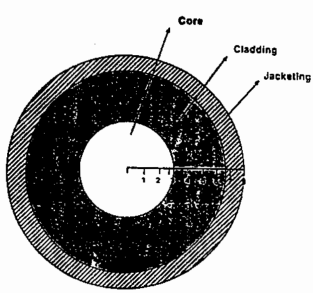
We have developed a numerical method for analyzing inhomogeneous optical fibers using finite differences. The method does not use an iterative procedure to find the eigenvalues of the propagating modes as opposed to the earlier works in this area.

The propagation characteristics of an optical fiber, under the 'small index gradient' and 'weakly' guiding approximation' is governed by the Bessel differential equation. Various grid points were chosen along the radial direction (see Fig. below) and finite difference equations are written at these grid points. The set of finite difference equations can be put into a matrix equation of the form $\mathbf{A}\mathbf{u} = 0$. The elements of the matrix $\mathbf{A}$ are functions of the width of the grid, refractive index at the grid points, the normalized frequency and propagation constant. $\mathbf{u}$ is a column vector whose elements are the eigenfunctions at the grid points. The problem is converted into an eigenvalue problem by post multiplying the matrix equation by $\mathbf{P_1}\mathbf{P_1^{-1}}$, where $\mathbf{P_1}$ is a transformation matrix defined for the problem such that the matrix equation can be rewritten as an eigen equation $[\mathbf{T} - \alpha\beta\mathbf{I}]\,\mathbf{v} = 0$. Here, $\mathbf{T}$ is a tri-diagonal matrix, β is the propagation constant which we are interested in, $\mathbf{I}$ is an Identity matrix, $\mathbf{v} = \mathbf{P_1^{-1}}\mathbf{u}$ is a vector whose elements are a linear combination of the elements of the vector $\mathbf{u}$, and α is a constant. We see that the propagation constant can be easily computed by finding the eigenvalue of the tri-diagonal matrix.



MODAL ANALYSIS OF COUPLED OPTICAL FIBER CORES WITH RADIALLY ARBITRARY INDEX PROFILES BASED ON THE CIRCULAR HARMONICS EXPANSION METHOD

Chih-Sheng Chang and Hung-chun Chang*

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Circular harmonics expansion method has been used to solve the guided modes propagating on a composite two-core fiber in which the cores have step refractive-index distributions and the cladding is uniform (Wijngaard, *J. Opt. Soc. Amer.*, 63, pp. 944–950, 1973). In the method the fields in the cores are expanded in terms of the Bessel functions and those in the cladding in terms of two sets of the modified Bessel functions corresponding to the two cores, respectively. In this paper we show that this method can be generalized to treat the coupled structure in which the cores have radially arbitrary index profiles and an efficient and accurate numerical model is thus established. The main feature in the proposed formulation is that the circular harmonics expansion method is combined with any available numerical method (finite difference, finite element method, etc.) which could provide the modal properties of the individual single-core fibers. In our model the finite element method is employed. Modal cutoffs of the higher-order modes can also be determined under this formulation if the fields in the cladding are expanded in terms of the eigenfunctions of the Laplace equation in cylindrical polar coordinates, similar to that discussed in a separate paper presented by the same authors in the accompanying IEEE AP-S Symposium. Figure 1 shows the geometry of the cross section of the coupler structure in this study. Figure 2 gives one of the numerical calculations: the normalized propagation constant B versus the normalized frequency V for the first two modes of the coupler composed of two touching ($D = d/(a_1 + a_2) = 1$) identical cores with α-power index distributions for $\alpha = 1, 2, 10$, and ∞ (step-index). Here, we consider scalar modes. Vector modes can be calculated using the same formulation.

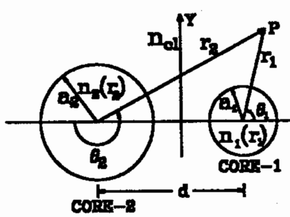

Figure 1

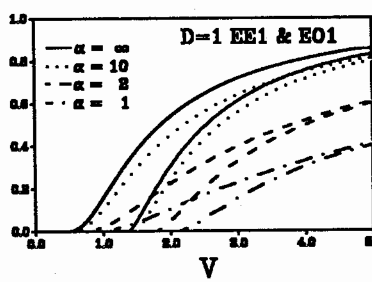

Figure 2

A NUMERICAL PROCEDURE USING THE SHIFTED POWER METHOD FOR ANALYZING DIELECTRIC WAVEGUIDES WITHOUT INVERTING MATRICES

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For a transversely inhomogeneous dielectric waveguide a transverse field ψ satisfies the scalar wave equation

$$\nabla_t^2\psi(x,y) + [k_0^2\epsilon(x,y) - \beta^2]\psi(x,y) = 0, \tag{1}$$

where $k_0^2 = \omega^2\mu_0\epsilon_0$, $\epsilon(x,y)$ denotes relative permittivity distribution, and β is the propagation constant in the axial direction. Applying the finite-difference technique the partial differential equation becomes the linear algebraic simultaneous equations:

$$\frac{1}{\Delta^2}\left\{\psi_{i+1,j} + \psi_{i-1,j} + \psi_{i,j+1} + \psi_{i,j-1} - 4\psi_{ij}\right\} + k_0^2\epsilon_{ij}\psi_{ij} = \beta^2\psi_{ij}, \tag{2}$$

where $\psi_{ij} = \psi(i\Delta,j\Delta)$, $\epsilon_{ij} = \epsilon(i\Delta,j\Delta)$, and Δ is a small increment in length.

For a fixed value of k_0 the simultaneous equations can be arranged to the form of *standard eigenvalue problem*:

$$\mathbf{A}\mathbf{x} = \beta^2\mathbf{x}, \tag{3}$$

where $\mathbf{A}$ is a matrix, and β^2 and $\mathbf{x}$ are the eigenvalue and eigenvector to be found. The largest eigenvalue in magnitude and its eigenvector can be found using the power method. However an actual calculation gives the largest eigenvalue in magnitude of, approximately, $-8/\Delta^2$. Apparently, this eigenvalue is unphysical. By noting the terms in the brace of (2) it is seen that this spurious mode originates from the finite-difference scheme.

In order to avoid this trouble one of the popular approaches is to fix the constant β and arrange the simultaneous equations to the *generalized eigenvalue problem*:

$$\mathbf{B}\mathbf{x} = k_0^2\mathbf{C}\mathbf{x}. \tag{4}$$

In this form the interesting eigenvalues are the smallest, which can be found using the inverse power method (or called the subspace iteration method for some variant). This approach requires one to invert or, equivalently, factorize the matrix $\mathbf{B}$ and hence is inefficient in both memory space and computer time.

The unphysical eigenvalues occur in the equation (3) can be avoided by shifting the eigenvalues as in the form:

$$\begin{aligned}(\mathbf{A}-sI)\mathbf{x} &= (\beta^2-s)\mathbf{x}, \\ &= \lambda\mathbf{x}\end{aligned} \tag{5}$$

where I is the unit matrix and s is a suitable constant. Let s be, say, $-8/\Delta^2$, then the largest eigenvalues λ will correspond to the dominant modes and can be found by the power method and its variants with simultaneous iteration. This method is more efficient, since the major computation is just the multiplication between matrix $\mathbf{A}$ and vector $\mathbf{x}$ or the operations on the left-hand side of (2). A drawback of the proposed method is that the convergence rate is slower.

Thursday AM

Joint AP-S, URSI-A Session 67

Adaptive & Signal Processing Arrays II

Chairs: R. T. Compton, Jr., The Ohio State University; Leland Langston, Texas Instruments Incorporated

Room: W-117 *Time*: 8:15-12:00

8:20	**A LMS and RLS Look-Ahead Adaptive Array for Spread Spectrum Signals** Robert G. Petroit, Donald R. Ucci*, Illinois Institute of Technology	AP-S
8:40	**A Multiple Array Solution to the Radomly Polarized Coherent Multipath Resolution Problem** Keith Struckman*, Sanders Associates Inc.	324
9:00	**Adaptive Polarization Direction Finding Methods** Brian S. Brown*, Texas Instruments Incorporated	AP-S
9:20	**An Efficient Multiple Source Localization Approach: Dynamic Programming** Yung-Dar Huang*, Mourad Barkat, State Univ of New York at Stony Brook	AP-S
9:40	**Direction Finding of Narrowband Autoregressive Sources by Antenna Arrays** Yeheskel Bar-Ness*, Ilan Ziskind, New Jersey Institute of Technology	AP-S
10:00	**Coffee Break**	
10:20	**Array Processing with Neural Networks for Multiple Emitter Bearing Estimation** Takeshi Manabe*, Satoshi Fujii, ATR Optical and Radio Communications	AP-S
10:40	**Superresolution Effects in Broadband Antenna Arrays** Sven Nordholm*, I. Claesson, P. Eriksson, University of Lund	AP-S
11:00	**Adaptive Phase Compensation for Distorted Phased Array by Minimum Sidelobe Response Criteria** Jenho Tsao*, National Taiwan University	AP-S
11:20	**Noise-Subspace-Approached Adaptive Beamformer Using Systolic Array Based on Givens Rotation** Shun-Hsyung Chang, Kuang-Chih Huang*, Chun-Yen Chang, National Sun Yat-Sen University	AP-S
11:40	**Bearing Estimation in the Presence of Near-Field Sources** Yih-Min Chen*, Ju-Hong Lee, Chien-Chung Yeh, National Taiwan University	AP-S

A MULTIPLE ARRAY SOLUTION TO THE RANDOMLY POLARIZED COHERENT MULTIPATH RESOLUTION PROBLEM

Keith Struckman

SANDERS
A LOCKHEED COMPANY

ABSTRACT

Coherent multipath signals can be resolved by a spatial smoothing superresolution technique (T. J. Shan, M. Wax and T. Kailath, "On spatial smoothing for direction-of-arrival estimation of coherent signals," IEEE ASSP-33, Aug. 1985). The spatial smoothing technique does not, however, steer beams that cancel the interfering multipath. This paper describes a new multiple array technique that resolves multiple coherent signals by adaptively weighting the array voltages and polarization responses as the direction vectors are steered. These weights are adjusted to maximize the correlation between the steering vector and the weighted signal vectors. A maximum is observed when the steering vector is pointed towards the direct path. At this maximum, the array is steered toward the direct signal and nulls are directed at the multipath.

This adaptive techinque is capable of reducing HF signal distortion created when HF signals travel through the ionosphere over several paths that introduce polarization shifts and time delays. Computer simulations are used to show adapted pattern resolution properties and the reduction in signal distortion achieved by multipath cancellation.

Thursday AM
URSI-B Session 68
Media Effects

Chairs: Dwight L. Jaggard, Nader Engheta, The University of Pennsylvania
Room: W-109 *Time*: 8:15-12:00

EXPERIMENTAL AND THEORETICAL STUDIES OF THE RELATIONSHIP BETWEEN HELIX GEOMETRY AND THE MACROSCOPIC CHIRALITY PARAMETER OF COMPOSITES CONTAINING RANDOMLY DISPERSED HELICES

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The Pennsylvania State University
University Park, PA 16802

Materials which lack inversion symmetry are characterized by the constitutive relations, $\mathbf{D} = \varepsilon\mathbf{E} + \beta\varepsilon\,\nabla \times \mathbf{E}$ and $\mathbf{B} = \mu\mathbf{H} + \beta\mu\,\nabla \times \mathbf{H}$. Such materials, called chiral or handed materials, exhibit a handedness in their microstructure. No systematic study has been made of the relationship between the geometry of the handed microstructure and the macroscopic properties. Theoretical models have been developed that relate the microscopic polarizability of such structures to macroscopic properties. Recently, the macroscopic properties for a series of laboratory samples containing left handed only, right handed only, and equal mixtures of right and left handed metal springs of known geometry and volume fraction have been obtained experimentally. Using the experimental data in conjunction with the theoretical model and the known geometry of the laboratory samples, relationships are obtained between geometry and macroscopic properties, especially the chirality parameter. Such relationships will be of great importance in tailoring the geometry of the microstructure for customized properties at microwave and millimeter wave frequencies.

AVERAGED ELECTRICAL PROPERTIES OF FINELY LAYERED BIANISOTROPIC MEDIA

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A stationary finely layered medium is equivalent, in the long wavelength limit, to a homogeneous medium. We derive a formulation, using matrix algebra and the basic elements of group theory, to calculate the constitutive properties of the equivalent homogeneous medium. Each thin (but varying thickness) layer is homogeneous and one of *n* different bianisotropic, and in general, nonreciprocal constituent media. The equivalent medium too will be bianisotropic and nonreciprocal. The *n* constituents are randomly distributed in such a way that there exists some minimum thickness *D*, much smaller than the wavelength of the insonifying electromagnetic wave, such that the relevant statistical properties of the distribution, in this case the *n* concentrations, are stationary when calculated over any layering thickness greater than *D*. A periodically layered medium is a special case of a stationary medium with *D* equals the period.

For any homogeneous constituent, the set of material properties maps into an element of a commutative group. A reverse mapping returns the material properties of the constituents. A simple addition of group elements gives the group element of the equivalent homogeneous medium. The power of this formulism lies in the fact that addition of an inverse element - subtraction - provides the means to remove a given constituent from a homogeneous medium. If the group element of the remainder corresponds to a stable homogeneous medium, a valid decomposition of the original medium into constituents is achieved.

Decoupled EM Plane Wave Reflection Coefficient for a Lossy Material Backed by a Conductor using Frequency Dependent Material Parameters

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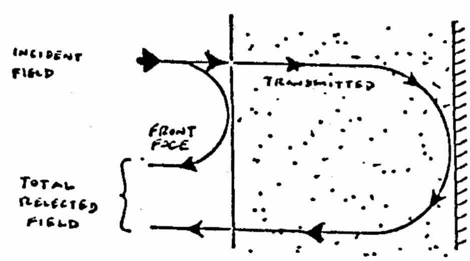
RADC/EECT
Target Characterization Branch
Applied Electromagnetics Division
Hanscom AFB, MA 01731

The reflection coefficient for a conductor backed slab of lossy material (Dallenbach absorber) is derived, and the expression is decoupled into *front face* and *travelling wave* terms. It is shown that for lossy materials the combination of these two terms gives a null for a single frequency or electrical thickness (product kd where k is the material wavenumber and d is the electrical thickness), and as kd increases, the total reflection reduces to the reflection from the front face. Reflection from this configuration will be shown for materials where dielectric loss is dominant and for materials where magnetic loss is dominant. The null location (in terms of λ) will be discussed for both of these cases. These results match those previouly published (E.F. Knott, IEEE Trans. Ant and Prop, Vol AP-27, No. 5, Sep 79). Most reflection analyses are for single frequency or assume that the material parameters are constant with respect to frequency. This analysis also considers the case where the material parameters are functions of frequency. Additonal resonances due to this variation are explored.



Modelling of Material Parameter Time Dependence for Radome Materials

R.L. Wittschen*, K.D. Trott and M.K. Hinders
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Hanscom AFB, MA 01731

The frequency and time dependence of material parameters of candidate radome materials is modelled by allowing for loss arising from relaxation-time phenomena. Measured broad band frequency data from a recently completed program is utilized for the materials of interest. This data is inverse Fourier transformed numerically to give time functions for complex μ and ϵ. These time functions are then approximated by a linear combination of damped exponential curves, each of which is characterized by an amplitude and a relaxation time, giving an expression for each of the form:

$$A_0 + A_1 e^{-t/\tau_1} + A_2 e^{-t/\tau_2} + \dots \qquad \text{for } t \geq 0.$$

The characteristic A_i, τ_i for each material are then tabulated, and can be used in a variety of time-domain scattering problems. In addition, the exponential series can be Fourier transformed in closed form using the one-sided transform of the exponential to derive a frequency dependence that conforms to existing models such as Debye's which gives for each mode

$$\epsilon' - j\epsilon'' = \epsilon^{\infty} + \frac{(\epsilon_i^s - \epsilon^{\infty})}{1 + j\omega\tau_i}.$$

MEAN WAVE PROPAGATION IN A SLAB OF ONE-DIMENSIONAL DISCRETE RANDOM MEDIUM

by

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A study has been made of the propagation of time harmonic waves through a one dimensional medium of discrete scatterers randomly positioned over a finite interval L. The random medium is modeled by a Poisson impulse process with density λ. In this model the scatterer positions are independent random variables, identically distributed. The invariant imbedding procedure is employed to obtain a set of stochastic differential equations for the field inside the slab and the reflection coefficient of the layer.

In the case where the reflection coefficient is known by using the Markov properties of the Poisson impulse process, an exact integro-differential equation of the Kolmogorov-Feller type is derived for the probability density function of the field. This result provides the basis for a rigorous verification of various formal approximate techniques such as Foldy's method.

On the specialization to the case where the concentration of the scatterers is low, a two variable perturbation method in small λ is used to obtain an approximate solution for the mean field. This solution, varying exponentially with respect to λL, is valid for any thickness of the layer. Further it is shown that the result compares exactly with the mean field obtained by Foldy's approximate method.

PADE' APPROXIMANT FOR ELECTROMAGNETIC SCATTERING FROM A CONIFEROUS FOREST

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A coniferous forest is modeled as a two-layer medium above a rough soil interface. The upper layer is the crown consists of leaves and branches. The lower layer is the trunk layer. The branches are represented by randomly oriented circular cylinders with different radii and lengths. The leaves are modeled as needles with a specified orientation distribution and number density. The trunks are modeled as randomly positioned vertical cylinders.

The first and second order solutions of the radiative transfer formulation for such a canopy is integrated by using the Pade' approximant to account for electromagnetic multiple scattering. The total scattering coefficient is expressed in terms of the scattering amplitude tensors of the leaves, branches, trunks and soil. The generalized Rayleigh Gans approximation is applied to obtain the leaf scattering amplitude tensor. The branch and the trunk scattering amplitude tensors are obtained by estimating the inner field by the fields inside a similar cylinder of infinite length. The Kirchhoff method is applied to calculate the soil scattering amplitude tensor.

Numerical results are presented for the backscattering coefficient to illustrate the differences between the first-order, second-order and the Pade' approximant at different frequency bands. Also, the effects of the orientation and number density for the leaves and the branches on the backscattering coefficient are investigated and the main characteristics of the coniferous forests are extracted. Finally, comparisons with field measurements are made.

WIRE SCATTERERS AND ANTENNAS IN CHIRAL MEDIA

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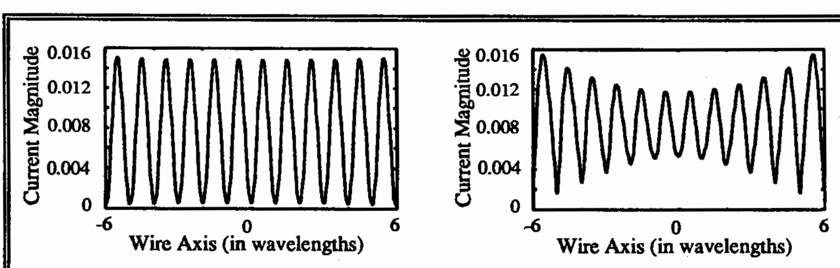
Electromagnetic chirality is found in materials characterized by the constitutive relations $\mathbf{D} = \varepsilon\mathbf{E} + i\xi_c\mathbf{B}$ and $\mathbf{H} = \mathbf{B}/\mu + i\xi_c\mathbf{E}$ for the electromagnetic field vectors **D**, **E**, **B** and **H** where, for the time harmonic case, ε, μ are the permittivity and permeability of the medium and ξ_c is the chirality admittance. This admittance is introduced to take into account the handedness properties of the material and its absolute value is the measure of material chirality. Chiral media is characterized by a pair of eigenmodes and their corresponding wavenumbers $k_\pm = \pm\, \omega\mu\xi_c + \sqrt{k^2 + (\omega\mu\xi_c)^2}$.

Here we examine the interaction of waves with metallic wire scatterers and radiators immersed in unbounded chiral media. Our interest is in the differential scattering cross section and the backscatter or radar cross section of such wires and the radiation properties of wire antennas in chiral media as a function of material chirality. The problem is formulated by developing the integral equation for the current, solving numerically and calculating the resulting scattered or radiated fields. As expected from physical considerations, the wires must be of sufficient length before chirality manifests itself in the induced currents although the two eigenmodes characteristic of the media can be excited by a variety of currents. In particular, two current modes characteristic of chiral media do not become evident for electrically short wires or dipoles but rather need larger structures in order to develop.

Shown below, as an example where chirality plays a role in the induced currents, is the current distribution on a thin wire illuminated by an incident plane when the wire is twelve wavelengths long. On the left is shown the achiral (non-chiral) case and on the right is displayed its chiral counterpart. Since the boundary conditions at the wire ends are the same in both cases, chirality manifests itself by changes in the current magnitude in the central portion of the wire. We find that chirality introduces additional spatial frequency components in the current distribution. Analogous effects are found for the case of wire antennas.



Achiral Wire Scatterer **Chiral Wire Scatterer**

CURRENT ON A LONG CYLINDRICAL ANTENNA IN CHIRAL MEDIA

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University of Pennsylvania
Philadelphia, PA 19104

Chiral materials, which belong to the class of *biisotropic* media, are described by the constitutive relations $\mathbf{D} = \varepsilon\mathbf{E} + i\xi_c\mathbf{B}$ and $\mathbf{H} = (1/\mu)\,\mathbf{B} + i\xi_c\mathbf{E}$. It is known that the characteristic plane waves propagating in a homogeneous chiral medium are right- and left-circularly polarized (RCP & LCP) waves, having differing propagation wave numbers.

In this talk, we examine analytically the current distribution on an infinitely long cylindrical antenna embedded in a homogeneous lossless chiral material. The antenna consists of a perfectly conducting, infinitely long, circular cylinder excited by a localized belt of axially directed monochromatic electric field at the surface of the cylinder. It is shown that due to the chirality of the surrounding material, the surface current density on the antenna has an extra azimuthal component in addition to the axial component. It is also shown that on such an antenna, the surface current density on either side of the source gap consists of two parts, each travelling away from the source with differing velocities. The relationship among these two parts, travelling velocities, and chirality of the surrounding medium is discussed and given. We present analytical expressions for these components of surface current density on this antenna. We also demonstrate the characteristics of the input impedance and far-zone radiated fields of such an antennas. The motivation behind the present investigation, besides its theoretical and academic importance, is provided by the physical insights gained from the results obtained in this study. Such insights would enable us to better understand and analyze thoroughly the problem of integral equation for the current induced in a finite-size wire antenna embedded in chiral materials. This problem is presently under study.

CURRENTS INDUCED ON PACEMAKERS BY EXTERNAL HF-FIELDS

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Artificial cardiac pacemakers are very effective tools in the therapy of cardiac diseases, a fact, which leads to an increasing number of patients living with implanted pacemakers. For a safe operation the voltage produced at the terminal of the pacemaker by an external source must not exceed a specified level. Further strong currents at the tip of the lead may produce unwanted heat. Therefore the electromagnetic field strength which may exist outside the human body without dangerous consequences must be determined. So far, there are many experimental and theoretical investigations for the frequency range up to some MHz, but less information for higher frequencies. The reason is that for lower frequencies the effect of the electrical and magnetical field can be treated separately and that the overall size of the body and especially of the pacemaker is much smaller than the wavelength. Both facts allow the application of simplified methods. This is not longer true for the VHF and UHF range.

Within the last ten years several numerical codes have been developed to calculate the specific absorption rate (SAR) of human bodies. Typically these start with a model of the body consisting of small homogeneous cells. In order to model correctly the box and the lead of the pacemaker inside the body, very small cells would be required, this would lead to extrem large sets of linear equations to be handled. Therefore, in order to get a first idea what happens we started with a pacemaker embedded in a two-dimensional model of the body consisting of two thin layers of skin- and of fat-tissue and a bigger layer representing the lung. The pacemaker is excited by a uniform plane wave of obliged angle of incidence. An integral equation for the currents on the pacemaker is formulated applying the exact Green's function of the multilayered media. This Green's function is determined with the help of Sommerfeld integrals, thus taking into account mutual coupling and the boundary condition in the interfaces. The integral equation is solved by the method of moments. As was to be aspected, the lead acts as an receiving antenna with a standing wave current distribution. From the current on the lead the voltage at the terminal of the pacemaker is calculated. Further the field distribution in the surrounding area is determined using again the Green's function. In order to discuss the heat produced per volume inside the tissue, lines of constant level of $|\vec{E}|^2$ are given.

Thursday AM

URSI-A,B Session 70

Array Analysis and Radiating Structures

Chairs: Robert S. Elliott, University of California; P. B. Katehi, The University of Michigan
Room: W-105 *Time*: 8:15-12:00

LEAKAGE AND RADIATION PROPERTIES OF COUPLED MICROSTRIP TRANSMISSION LINES

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Michigan State University
East Lansing, Michigan 48824

Accurate full-wave evaluation of dispersion and leakage properties of microstrip transmission lines is essential to the analysis of wave propagation and device interactions in micro/mm-wave integrated circuits operating at high frequencies. A rigorous full-wave integral equation formulation for the microstrip environments has been presented by the authors, and the dispersion and leakage properties of a single microstrip line have been studied [Y. Yuan and D.P. Nyquist, 1989].

In this paper, the dispersion characteristics and leakage properties of coupled microstrip transmission lines are investigated by the same full wave integral equation approach. It is found that, unlike the single strip line which has only higher-order mode leakage, the dominant mode of the coupled system can become leaky at high frequency due to the coupling effect. Consider the EH_0 system mode of two coupled microstrip lines as an example. When the two lines are wildly separated, the propagation eigenvalues approach that of the corresponding isolated-line limit. As the two lines become closer, the coupled system modes, symmetric and antisymmetric, emerge and split away from the isolated mode; when the two strips contact each other at the edges, the symmetric mode reverts to the EH_0 mode of an isolated strip with double width and the antisymmetric mode becomes the EH_1 mode of the same double-width strip. In certain circumstances, when the two strips are closely spaced, the propagation eigenvalue of the antisymmetric mode becomes complex, its phase constant falls below that λ_s of the surface wave of the associated layered structure: $\beta/k_0 < \lambda_s/k_0$, and the coupled mode becomes leaky. Power leaks away in surface wave form or space radiation when frequency becomes higher than certain critical frequency.

Numerical implementation for the coupled microstrip line is developed. Details of dispersion characteristics, leakage properties and current distributions are obtained and are compared with other published data whenever it is available.

SURFACE WAVE EXCITATION IN ANTENNA FEED NETWORKS

W.P. Harokopus*, W. Ali-Ahmad, G.M. Rebeiz, P.B. Katehi

Radiation Laboratory, University of Michigan, Ann Arbor, MI

Abstract-

Microstrip feed networks in monolithic array applications can exhibit high losses mostly associated with the power propagating in the substrate in the form of surface waves. These waves, which are cylindrical in nature, are excited in the vicinity of the microstrip discontinuities, and propagate away from them in selective directions. In large arrays operating at high frequencies, the substrate structure supporting the feed network and the radiating elements becomes electrically thick. As a result,the power propagating in these waves increases resulting in spurious coupling between the discontinuities in the feed network which in turn deteriorates the performance of the array considerably.

The understanding of the surface wave effects may become a critical factor in the successful design of a monolithic array by eliminating their excitation or use them to improve the array performance. To analyze these effects, an appropriate integral equation is considered which is solved numerically in the space domain using the method of moments. The microstrip feed network is assumed as made up of planar discontinuites such as Bends, Open Ends and Tee junctions printed on single- and multi- layer substrates. Initially, the discontinuities are studied as isolated circuit elements and the total power loss due to space and surface wave excitation is computed from the scattering parameters. In addition, stationary phase technique is applied to evaluate the percentage of the total radiated power launched into surface waves. In this manner, patterns are obtained for the dominant mode (TM_o) and first higher order mode (TE_o).

Upon completion of the theoretical study, experimental verification will be performed by comparing with far-field surface wave pattern measurements in isolated discontinuities. The edges of the substrate will be tapered to minimize the reflection of the surface waves and the field will be measured with an appropriate probe. Specifically, the surface wave radiation for an Open End, Bend, Tee junction and Cross junction will be analyzed and discussed extensively.

RADIATION MODES OF BIAXIALLY ANISOTROPIC SLAB WAVEGUIDES

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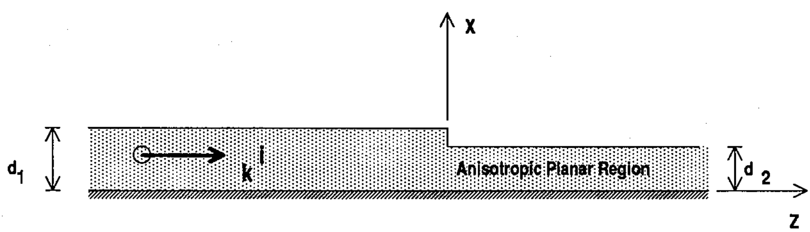
It is well known that the solution to Maxwell's equations for planar isotropic waveguides will consist of guided as well as radiation modes. These modal solutions may be used to expand an arbitrary field within the slab region, thereby allowing for the mathematical formulation of the waveguide boundary-value problem. However, for anisotropic slabs, solutions to Maxwell's equations have been, thus far, restricted to guided modes alone (D. Marcuse and I. P. Kaminow, "*Modes of a Symmetric Slab Optical Waveguide in Birefringent Media, Part II: Slab with Coplanar Optical Axis*", IEEE J. Quantum Elect., **QE-15**, no. 2, Feb. 1979, also see A. Knoesen et al., "*Hybrid Guided Modes in Uniaxial Dielectric Planar Waveguides*", J. Lightwave Tech., **vol. 6**, no. 6, June 1988).

In this paper, the radiation modes of a planar waveguide characterized by biaxial permittivity and permeability tensors, $\underline{\underline{\varepsilon}}$ and $\underline{\underline{\mu}}$, are derived. It is shown that they are orthogonal to one another, and may be normalized with the help of the delta function. To verify their correctness, scattering by a dominant guided mode impinging on a step junction of a grounded anisotropic slab (see Figure below) is considered. The step height is assumed to be small (compared to the wavelength) so that an approximate perturbation technique could be employed to solve for the radiation loss using either the guided or the radiation modes. The results obtained via the two methods must be identical, thus providing the means for validating the derived radiation mode expressions.



ABSTRACT

COMPUTATION OF S-PARAMETERS FOR MICROSTRIP-FED SLOT ARRAYS

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An attractive approach for high frequency array antennas is the use of cavity-backed slot radiators individually fed by shielded microstrip lines. Such an array has compact planar form which can be made conformal and also has well controlled radiation characteristics making it suitable for high performance applications. Each element is fed by a microstrip line which passes through the cavity wall. The microstrip lines are driven by a main feed line through a series of directional couplers whose coupling ratios, together with the cavity/slot/microstrip geometries, are used to control the amplitude and phase taper of the array. The slots are covered by a dielectric material which acts as a radome and whose thickness can be used to control the mutual coupling between elements.

A brief description of the full-wave analysis of the cavity elements is given based on an integral equation formulation. A generalized dyadic Green's function for cavities is used, allowing multi-layered microstrip structures as may be required by additional circuit elements for active antennas or functions such as phase steering. The equations are solved using conventional Method of Moments techniques.

The formulation for finding the S-parameters of the individual elements is presented based on the Reaction Theorem. The method employs the solution for the fields in multi-layered shielded microstrip which are found from an integral equation involving the Green's function for layered waveguide and the modal current on the strip. Application to the special case of stripline is presented in comparison to measured data.

POWER LEAKAGE FROM THE DOMINANT MODE ON COPLANAR WAVEGUIDES WITH FINITE OR INFINITE WIDTH

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and

A.A.Oliner
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It is not generally known that above a certain critical frequency the dominant mode on uniform coplanar waveguides will leak power into a surface wave on the outer portions of the waveguide or the support structure. In an integrated circuit context, this leakage can result in significant cross talk and power loss. Furthermore, the leakage effects are different when the lateral extent (width) of the outer plates is finite or infinite. We describe here the nature of the power leakage and the reason for it, and we show in what ways the guide width influences the leakage effects. Most of these features are presented here for the first time.

The simplest case is encountered when the outer plates of the coplanar waveguide (CPW) are ***infinite*** in width. Away from the central region of the CPW we then have a ***grounded*** dielectric layer of height equal to that of the substrate, on which the lowest surface wave is the TM_0 mode. Leakage then occurs above the frequency at which the dispersion curves for the CPW dominant mode and the TM_0 surface wave cross each other, and the power leaks at an angle to the guide axis in the form of the TM_0 surface wave. This leakage has not been reported previously in the literature.

When the outer metal plates are ***finite*** in width but the dielectric substrate layer extends laterally indefinitely, the outer structure is an ***ungrounded*** dielectric layer whose lowest surface wave is the TE_0 mode. Above the frequency corresponding to the crossing of the dispersion curves for the CPW dominant mode and the TE_0 surface wave on the ungrounded substrate, we will find leakage from the dominant mode into the TE_0 surface wave. Note that the conditions for leakage in the finite-width and infinite-width cases involve different effective structures (one grounded and the other ungrounded) in addition to different surface waves.

Other physical effects also appear when the plate width is finite, such as coupling to a second dominant mode, and a standing surface wave (laterally) under the outer plates if the leakage condition for the infinite-width case occurs at a lower frequency than that for the finite-width case, which is usual. We will present accurate quantitative data (obtained by employing an improved mode-matching procedure) for the dispersion behavior and the leakage constants as a function of frequency for all of these cases.

TRANSITION-REGION BEHAVIOR OF A NEW LEAKAGE EFFECT ON MICROSTRIP LINES WITH ANISOTROPIC SUBSTRATES

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and

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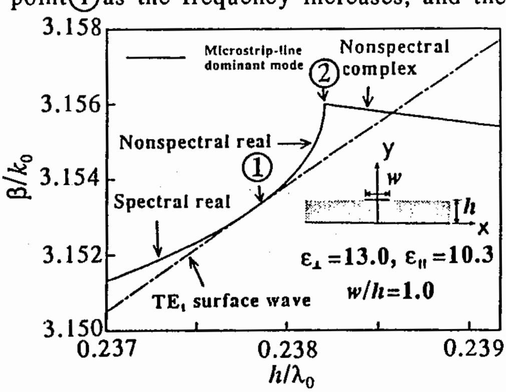
We were the first to report (at the 1989 International Microwave Symposium) that the dominant mode on uniform printed-circuit waveguides could exhibit a new class of power leakage effects when anisotropic dielectric materials are used as substrates.

As an example of such waveguides, let us here consider microstrip line when the c-axis of an anisotropic substrate is perpendicular to the substrate surface. Then the microstrip line dominant mode has its electric field predominantly along the c-axis. Since the waveguide also includes the conductor-backed dielectric slab regions extending semi-infinitely outside the strip, those regions can also support the dominant TM_0 surface wave at all frequencies (its polarization is the same as that of the microstrip line mode) and the TE_1 surface wave above its cutoff frequency (its polarization is perpendicular to the c-axis). When the c-axis permittivity is lower than the permittivity in the plane perpendicular to this axis, an inversion occurs at a certain high frequency in the relative phase velocities between the microstrip line dominant mode and the TE_1 surface wave, and the microstrip line dominant mode *leaks* power at an angle into the TE_1 surface wave at frequencies *above* this inversion, or crossing, frequency.

This crossing region involves a *complicated transition* between a spectral real solution and a nonspectral complex solution. The figure shows an example of our calculations when Epsilam 10 is used as the substrate; it indicates the behavior of the normalized phase constant β/k_0 with the frequency. Our calculation, based on an improved mode-matching method, shows that the solution, which is *real* at low frequencies, reaches the dispersion curve of the TE_1 surface wave at the point ① as the frequency increases, and then continues as a *nonspectral real* solution. At the frequency indicated by ②, it connects with a *nonspectral complex* solution which corresponds to the new leaky wave on the microstrip line explained above. Somewhat similar complicated behavior has been found in corresponding transition regions from leaky waves to surface waves, but here the frequency ranges are reversed and the behavior is more involved, as will be explained in the talk.



The Short Circuit and Load for the Moment Method Solution of a Microstripline

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It has been shown (Y.L. Chow, MTT-28, 1980, 393-397) that a microstripline can be taken as a bent linear antenna and is solvable by the moment method of Harrington with a quasi-dynamic Green's function.

This quasi-dynamic Green's function has been shown to be accurate even for complex circuits like spiral inductors and amplifiers (M.G. Stubbs et. al. Proc. 17th EMC, Rome, Italy, 1987, 273-279). For good agreement with experiment it is necessary to construct good loads and good short circuits for the moment method.

The construction can be understood from Harrington's moment method formulation of the impedance element Z_{mn}:

$$Z_{mn} = j\omega\mu\overrightarrow{\Delta l}_m \cdot \overrightarrow{\Delta l}_n \psi^F_{mn} + \frac{1}{j\omega\varepsilon}\left(\psi^C_{\substack{++\\mn}} - \psi^C_{\substack{+-\\mn}} - \psi^C_{\substack{-+\\mn}} + \psi^C_{\substack{--\\mn}}\right)$$

For linear antennas, the potentials $\psi^F_{mn} = \psi^C_{mn}$. For microstriplines one simply adds to ψ^F_{mn} and ψ^C_{mn} different contributions from current and charge images (Chow, Ibid.).

Harrington's formulation requires all segments to be butting against each other. This means that a load Z_L to ground at the end segment n must be an extra vertical segment as shown in Fig. 1. This vertical segment may not be realistic. It is desirable therefore to delete the vertical segment, create a "current sink" at the end segment n and to add the load Z_L to this horizontal end segment as shown in Fig. 2.

The adding of the load Z_L to segment n is obvious. The "current sink" is also simple to create by setting to zero all charge potentials $\psi^C_{\substack{+\pm\\nm}}$ in the above equation.

This paper gives physical explanations to such simple constructions for Z_L and the short circuit. A number of examples will be shown.

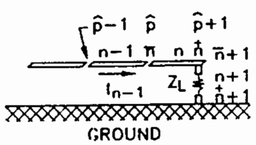

Figure 1 The line and vertical load.

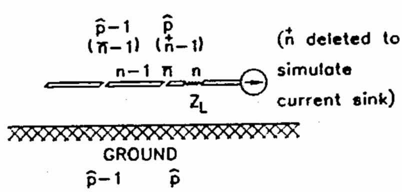

Figure 2 The line, load and short.

A LINEAR PHASED ARRAY OF DIELECTRIC-FILLED SLITTED ASYMMETRIC RIDGE WAVEGUIDES

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A novel phased array of parallel leaky-wave line sources for millimeter waves was described few years ago (P. Lampariello and A. A. Oliner, European Microwave Conf., Rome, Italy, pp. 555-560, 1987) that presents some very interesting features, such as the absence of cross polarization, no blind spots, and no grating lobes. These interesting features were obtained by introducing vertical metallic baffles to separate the line sources. Recently, we studied the characteristics of a novel leaky-wave line source based on a dielectric-filled, slitted asymmetric ridge waveguide. Our analysis indicates that this antenna indeed has very flexible electrical characteristics. In this paper we propose a phased array composed of such line sources separated by vertical metallic baffles. The benefic effects of the baffles are retained and a very versatile millimeter-wave phased array is thus obtained.

The single line source consists of a dielectric-filled ridge waveguide where the heights of the two arms of the guide are unequal. The top wall exhibits a centered, longitudinally continuous slit and the side walls are prolonged with vertical baffles. Because of the asymmetry introduced on the ridge waveguide, a horizontally polarized electric field is excited in the air-filled upper stub of finite height. The presence of the dielectric allows us to make the distance between the baffles less than $\lambda_0/2$, so that the higher order modes are all below cutoff and therefore only a negligible cross polarization is present if the baffles are sufficiently long. Moreover the constraint on the distance between baffles automatically avoides grating lobes.

When a number of parallel line sources are put together, a two-dimensional scan is achieved by imposing a phase shift between successive parallel radiators in the array.

We present here an accurate transverse equivalent network for this phased array that employs a unit-cell approach; in this way all mutual couplings are rigorously taken into account. A transverse resonance equation is then derived whose solutions furnish the performance characteristics of the array. The results obtained show that a conical scan is achieved without blind spots and confirm the flexibility of the structure; in fact, by varying suitable geometrical parameters, it is possible to control independently the direction of maximum radiation and the beam width.

A STRUCTURED ALGORITHM FOR THE SYNTHESIS OF PLANAR ARRAYS

E.Botha* and D.A.McNamara

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Experience with existing numerical procedures for planar array synthesis soon reveals that, in spite of statements to the contrary, there is still much reliance on a cut and try approach. Although various exact and numerical synthesis techniques exist that yield the excitation for a linear array (or one-dimensional sequence), these techniques and expressions do not generalize to the processing of general two-dimensional sequences (or planar arrays), primarily due to the absence of a two-dimensional factorization theorem.

A transformation to represent two-dimensional sequences as one-dimensional sequences (R.M.Mersereau & D.E.Dudgeon, IEEE Trans., vol.ASSP-22, pp.320-325, 1974) has been applied to represent rectangular planar arrays (with the elements laid out on a rectangular grid) as equispaced linear arrays in tandem. We will refer to the latter as the **equivalent composite linear array**. The advantage is that the above transformation effectively specifies the planes in which the planar array pattern has to be sampled; this alleviates the problem associated with sampling in the principal and additional arbitrarily chosen planes leading to incorrect pattern behaviour in intermediate planes. This sampling supplies the pattern required of the equivalent composite linear array. A linear array synthesis procedure is then used to synthesise the equivalent composite linear array which will provide the above pattern, and the linear array elements are then inverse-transformed to the original planar array configuration.

In the presentation the results which have thus far been obtained using the above approaches will be described and evaluated.

THE EXTERNAL CONTRIBUTION TO THE SCATTERING FROM AN ANTENNA ARRAY OF SLOTS

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The radar cross-section of a slot antenna array can be conveniently divided into an internal contribution dependent on the feed network connected to each slot, and an external component due to scattering from the conducting portions making up the face of the array. In view of the increasing interest in the radar cross section of antennas some way of estimating these effects is clearly desirable. By considering each slot to be the opening of an "inlet" recently published techniques for intake geometries (H.Ling, S.W.Lee & R.Chou, IEEE Trans., vol.AP-37, pp.648-654, 1989) might be used for determerming the internal contribution. In this paper a method will be discussed for finding the external contribution.

The array face is first considered to be infinitely large, and to consist of a doubly periodic planar array of rectangular slots in an infinitely thin groundplane. A moment method solution is used to determine the current distribution over the conducting portion of each unit cell. This current distribution is then used along with an appropriate array factor to determine the external contribution to the scattering from an actual finite array.

In the presentation the measured (on a compact range) and calculated results which have thus far been obtained using the above approaches will be described and evaluated.

Thursday AM
Joint AP-S, URSI-A Session 74
Transient Measurements

Chairs: E. V. Jull, University of British Columbia; E. K. Walton, The Ohio State University

Room: W-115 *Time*: 8:15-12:00

ABSTRACT

Application of a Layer-Peeling Technique to Identify Dielectric Constants of Stratified Media

by

S. Giles
University of Toledo

This paper is concerned with the identification of the position and dielectric constant of simple stratified media. Reflection coefficients are obtained from information contained primarily in the reflected time signal resulting from a known incident signal striking the media. Actual measurements are done in the frequency domain over an eighteen gigahertz bandwidth and Fourier transformed to the time domain. The theory of the technique is presented; and actual results are given for stratified particle boards and polyethylene slabs.

ACTIVE E-FIELD SENSOR FOR MEASUREMENTS OF TRANSIENTS

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In measuring transient and pulsed electromagnetic fields, one requires electrically small antennas which can operate in a very wide frequency range with minimal perturbation to the measured field. When amplifiers or other active components are incorporated into the antenna, the whole system becomes an active sensor. The sensors for transient field measurements should have a wide dynamic range, well-defined directional responses and minimal response to the unwanted field quantities.

From the two types of possible sensor responses, we have selected the one proportional to the field rather than to the derivative of the field. The active E-field sensor utilizes a spherical antenna with two high input-impedance buffer amplifiers and a differential amplifier located inside the sphere. The antenna consists of two identical hollow plastic hemispheres which were silver-coated inside and attached to each other around the perimeter. The top point of each hemisphere was connected to a buffer amplifier using a large diameter cylindrical conductor. Two sensors have been investigated with upper frequencies of 500 MHz and 1 GHz respectively.

A monopole configuration of the 500-MHz sensor was manufactured, tested and calibrated in a TEM cell in both the frequency domain (using HP 3577A and HP8510B network analyzers) and the time domain (using a PSPL 1000C impulse generator, a Tektronix 7912HB digitizing oscilloscope and a Compaq 386/20 microcomputer). A Tektronix P6501 microprobe was used as a buffer amplifier. The time domain data were converted into the frequency domain using complex FFT and compared with the results in the frequency domain. The performance of the sensor was also modelled using a computer simulation program SPICE. The results of the three methods show that the sensor gives a flat output response with 1 mV/(V/m) sensitivity from 10 kHz to almost 400 MHz. The rise time of the output pulse is less than 500 ps.

ANALYSIS AND MEASUREMENT OF ACOUSTIC PULSE DIFFRACTION

G.R. MELLEMA, M.J. YEDLIN, ZHANG QIN AND E.V. JULL*
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and Geophysics and Astronomy
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Vancouver, Canada V6T 1W5

Diffracting edges produce characteristic signatures in seismic records. These may indicate the prescence of geological faults and associated hydrocarbon traps. Here numerical and experimental models of acoustic pulse diffraction by structures involving edges are described. The structures studied are plane and curved half planes and step discontinuities.

The uniform geometrical theory of diffraction is used in the analysis. Consequently the discontinuities analyzed at present are not small in wavelengths. The experimental arrangement uses commercial audio frequency equipment and a personal computer to produce a swept frequency source signal which is later cross correlated with the return signal to eliminate the limitations of the loudspeaker response. Signal processing of the return is used to enhance the diffraction hyperbolas. The result is an inexpensive but remarkably effective system for identifying diffracting edges. Ridges as small as 0.3 mm. on a smooth plane are detectable at audio frequencies with this system.

Numerical and measured results agree well for simple structures so the experimental facility can be expected to provide verification of synthetic results for more complicated structures.

BROADBAND TRANSIENT ELECTROMAGNETIC SCATTERING LABORATORY

Michael A. Morgan
Electrical & Computer Engineering Department
Naval Postgraguate School, Monterey, CA 93943

Norman J. Walsh *
National Defense Headquarters, DLAEEM 4-9
Ottawa, Ontario, Canada, K1A 0K2

A brief historical review of the Transient Electromagnetic Scattering Laboratory (TESL) at the Naval Postgraduate School is presented. This is followed by a discussion of the theory and operation of the current free-field facility.

Implementation of state-of-the-art technology and a novel impulse generation system has significantly enhanced both the bandwidth and the signal to noise ratio of TESL measurements within the last year. This upgrade combines a new digital processing oscilloscope receiver with a specially constructed dual GaAs FET parallel amplifier transmission system. The resultant system provides real-time transient scattering responses with a frequency bandpass exceeding 1 to 12 GHz. Details of the problems and solutions accompanying this recent enhancement are considered and example validations are shown which illustrate the high level of fidelity attainable.

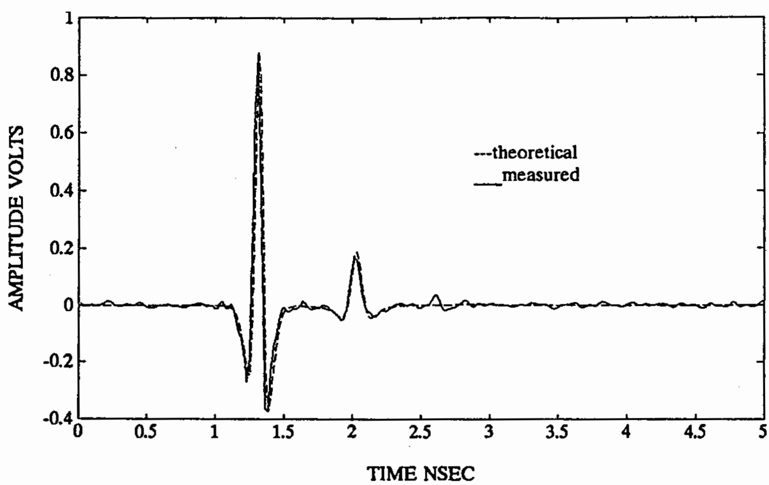

Figure 1 Transient Backscattering by an 8 cm Diameter PEC Sphere

An Incident Field Sensor for EMP Measurements

Everett G. Farr*
EMA, Inc.

Joseph S. Hofstra
BDM International, Inc.

When making field measurements at EMP simulators, one needs broadband antennas that are flat to above 100 MHz. In addition, it would be helpful if these antennas were directional, in order to reject reflections from directly behind the sensor. This becomes important in extrapolation procedures that correct for differences between the field generated by the simulator and an actual threat field (E. G. Farr, Sensor and Simulation Note 311, 1988). Currently available antennas, however, are short dipoles and small loops, which are omnidirectional in one plane. The purpose of this paper is to report on the development of an antenna that solves this problem with a 1 + cos(theta) antenna pattern in both the E- and H-planes. We call this antenna the Balanced Transmission-line Wave (BTW) sensor.

The design of the antenna is based on the idea that if one could sum the antenna patterns of a short dipole and a small loop, one could achieve a directional sensor. A technique was proposed some time ago to implement this (J. Yu, et. al., Sensor and Simulation Note 243, 1978), but the device was never built and tested.

In this presentation, a simple theory of operation is discussed. Furthermore, experimental results are presented for a prototype sensor. A Front/Back ratio of 20-29 dB was achieved in field measurements. These results confirm the principal of operation of the sensor, and encourage further engineering development.

TIME DOMAIN ANTENNA CONCEPTS

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Antennas to be used in a video pulse radar are to be discussed. Such radars are used ever more frequently for ground penetrating radars (GPR). A major goal is to achieve as much isolation between transmitter and receiver as is practical before any processing. To date, the scheme that best achieves this role has been the crossed dipole where the orthogonality properties of the two antennas are used to achieve isolation. This has the advantage of detecting only nonsymmetrical targets. For geological exploration, it would not detect interfaces parallel to it.

A novel GPR antenna was constructed by using separate parallel transmitting and receiving antennas mounted on a resistive sheet. The transmission and reflection characteristics of this antenna are compared to those of the more conventional antennas, including one that is used on a commercial system. It is found to yield results comparable to those of the crossed dipole, except, of course, parallel interfaces become detectable.

One of the major difficulties with antennas to be used with video pulse antenna is the bandwidth properties. Usually the antenna provides a filtering characteristic. Conventional very broad antennas, spirals etc. become dispersive and require data processing to preserve the pulse width. Several schemes for providing broad band antennas are to be discussed.

BISPECTRAL ANALYSIS OF RADAR SIGNALS

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ElectroScience Laboratory
Electrical Engineering Department
The Ohio State University
Columbus, Ohio 43212

Time domain (or range domain) analysis of the scattering from a radar target is typically done using the impulse response, (the inverse Fourier transform (IFT) of the frequency domain response). The result is a range profile which can display the scattering from the radar target as a function of range (or time), but which provides no information about the relationship between the various range (or time) domain responses. It is not possible, for example, to distinguish single mode specular scattering from multiple interactions. This paper will present an application of a signal processing technique called the Bispectrum which can be used to study such interaction effects.

The Bispectrum $B(\omega_1, \omega_2)$ of a time series is often computed by taking the two-dimensional Fourier transform of a triple product of the time series data $\{x(t)\}$ with two delayed versions.

$$B(\omega_1, \omega_2) = IFT(R(\tau_1, \tau_2) = E\{x(t)x^*(t+\tau_1)x^*(t+\tau_2))$$

Radar scattering data, however, is not time series data, but is given in the frequency domain. Its Bispectrum is a mapping to the two dimensional time domain (or 2-dimensional range domain using $t = 2r/c$ where t and r represent the time and range to the target respectively). In this two dimensional mapping, a response at $(range_1, range_2)$ indicates the magnitude of the interaction between scatterers at $range_1$ and those at $range_2$.

In this paper, we will show Bispectral mappings based on both a simple three-scatterer model and on data from experimental measurements. It will be shown that the Bispectral mapping into the bi-range domain results in responses which can be interpreted in terms of both single specular reflections and multiple interaction terms. In many cases, it is actually possible to distinguish between the interaction terms and the single scatterer terms; a distinction not possible with the impulse response.

Thursday AM
URSI-B Session 75
Asymptotic Techniques

Chairs: S. W. Lee, University of Illinois; R. J. Marhefka, The Ohio State University
Room: W-104 *Time*: 8:15-12:00

DEVELOPMENT OF NUMERICAL ELECTROMAGNETIC-BASIC SCATTERING CODE FOR SPACE STATION APPLICATIONS A DESCRIPTION AND ANTENNA CHAMBER EVALUATION

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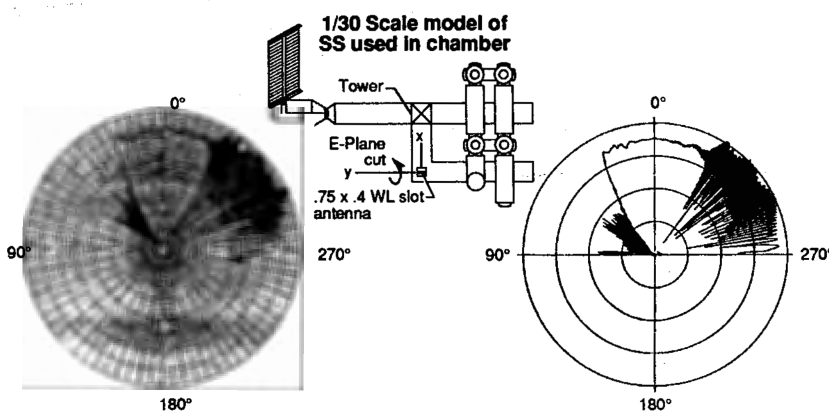
A brief description of the Numerical Electromagnetic Code - Basic Scattering Code (NEC-BSC Version 3.1), along with results of a comparative evaluation of calculated far-field patterns, with patterns measured in an antenna chamber are presented. The NEC-BSC program is a user-oriented computer code for the electromagnetic analysis of radiation from antennas in the presence of complex structures at UHF frequencies and above. The code can be used to predict near- or far-zone patterns of antennas in the presence of scattering structures. Simulation of the scattering structures is accomplished by using combinations of multiple flat plates, elliptic cylinders, cone frustums, and ellipsoids.

The analysis is based on uniform asymptotic techniques formulated in terms of the Uniform Geometric Theory of Diffraction (UTD). Essentially any antenna type can be defined since the UTD solutions are based on infinitesimal elements. A number of antenna types, such as dipoles, and rectangular and circular apertures are defined in the program. The code has been successfully used to model a wide range of problems, such as scattering from living quarters and structures of a Space Station (SS), using plates and curved surfaces. A description of the code's many other features and its operation are included in a Users Manual which is available upon request.

Using a precision 1/30 scale model of the middle section of the SS, antenna pattern measurements were made at 60 GHz in a compact range for both broad and narrow beam antennas. Patterns were calculated at 2 GHz, using the NEC-BSC code simulating the full-scale SS, and the same antenna types as used for the measurements. Excellent agreement was obtained between calculated and measured patterns as shown in the figure for a principal E-plane pattern.



Measured Pattern

Calculated

Eliminating Spurious Shadow Boundary RCS Contributions from Physical Optics Solutions for Coated Bodies

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1406 W. Green Street, Urbana, Illinois 61801

In high-frequency applications physical optics (PO) has an advantage over geometric optics in that numerical integration of surface currents over an approximate surface representing a body is easier in many cases than determining the specular ray scattering from a body. For plane wave scattering from a smooth convex body, the transition from the "lit" region of the body to the "shadow" region is, in general, a gradual transition. The PO solution, however, is based on a lit region where the surface currents are nonzero, and a shadow region in which the surface currents are zero. The sharp boundary between the lit and shadow regions is a nonphysical characteristic of the surface currents. Therefore, the contribution to the scattered fields from this nonphysical truncation of the surface currents is not necessarily valid. These scattered field components from the shadow boundary can in some cases be removed by subtracting the "PO diffracted fields" from the PO solution.

The PO diffraction coefficients for determining the PO diffracted fields from curved perfectly conducting bodies were derived by Gupta and Burnside (AP-35, May 1987, pp. 553-561). This work will present a formulation of the more general PO diffraction coefficients for a curved coated body. These diffraction coefficients will be applied to scattering from bodies of revolution to remove the spurious PO components from scattered fields from coated bodies.

ELECTROMAGNETIC SCATTERING BY METALLIC TAPES ON PANELED COMPACT RANGE REFLECTORS

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In present day compact range systems the main reflector may be physically very large for operation over a large bandwidth necessitating the need for the reflector to be manufactured in sections. Once these paneled sections are aligned, one can use metallic tape to cover the inter-panel gaps. It is therefore of interest to study the effect of the scattering by the tape on the fields in the target zone of the range. The scattering by a metallic tape on a reflecting surface was previously examined in two dimensions (2-D) by the method of moments and an empirical study was presented to indicate the effect of the tape as a function of tape dimensions,[I.J. Gupta and W.D. Burnside, AMTA Conference, Monterey, Calif., Oct. 1989, pp. 15-35–15-39]. However that procedure is computationally time consuming and difficult to apply to the 3-D situation.

In this paper, an analytical solution is presented for the scattering by the 2-D tape configuration via the generalized scattering matrix technique used in conjunction with the Wiener-Hopf procedure. The 2-D analytical solution is compared with a reference moment method solution to confirm the accuracy of the former. In addition, the solution is also compared to the simpler physical optics approximation to determine the range of validity of the latter. The analytical result for the 2-D tape scattering configuration is then extended to treat the corresponding 3-D case by using the concept of incremental diffraction coefficients [R. Shore and A. Yaghjian, IEEE T-AP, Vol. 36, No. 1, Jan. 1988, pp. 55–70] over a finite region.

The present solution obtained for analyzing the scattering by 3-D rectangular perturbations also has applications in RCS prediction if they are present on otherwise low cross-section platforms.

APPLICATION OF THE GENERALIZED RAY EXPANSION METHOD TO ANALYZE THE EM SCATTERING BY ARBITRARY OPEN-ENDED WAVEGUIDE CAVITIES

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The generalized ray expansion (GRE) method was developed recently to analyze the complex problem of EM scattering by large open-ended waveguide cavities of relatively arbitrary shape. Basically, the scattering from just the open end alone can be found via the geometrical theory of diffraction (GTD) used in conjunction with the equivalent current method (ECM), whereas, the field scattered into the exterior due to the presence of the interior waveguide termination is found by discretizing the aperture at the open end into a relatively small number of sub-apertures and by launching the rays from each sub-aperture into the cavity with the initial ray amplitudes weighted by the far field radiation pattern of the sub-aperture. This approach has the advantage that, unlike the conventional GO ray shooting approach, the GRE method launches and tracks a grid of rays within the cavity just once, independent of the external plane wave incidence angle, and the fields diffracted into the cavity by the edges at the open end are implicitly included in the analysis.

The basic ideas of the GRE were illustrated by solving the scattering by relatively simple 2-D semi-infinite open-ended waveguide geometries with an interior termination [P.H. Pathak, et al., IEEE APS International Symposium and URSI Radio Science Meeting, San Jose, Calif., June 1989, pp. 840-843, and P.H. Pathak, R.J. Burkholder, URSI International Symposium on EM Theory, Stockholm, Sweden, August 1989, pp. 181-183]. In the present paper, the GRE approach is extended to treat the far more general situation of EM scattering by relatively arbitrary 3-D semi-infinite open-ended waveguides with an interior termination. Specifically, the general rules required for estimating the relative sizes and shapes of the sub-apertures and the number of ray-tubes launched from each sub-aperture are developed for the 3-D case, and the general conditions for the applicability of the GRE procedure are obtained. Numerical results will be presented which illustrate these extensions of the GRE as applied to the scattering analysis of several specific 3-D open-ended cavity geometries, such as a cavity with a linealy tapered rectangular cross-section, an S-shaped cavity with a constant rectangular cross-section, an S-shaped cavity with a cross-section transition from rectangular to circular, etc.

ELECTROMAGNETIC PLANE WAVE DIFFRACTION BY A WIDE AND THICK SLIT

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Because of its simple shape, aperture diffraction of electromagnetic waves has been investigated by many authors and reported in various literature. When an infinitely thin slit is composed by two half planes, it would be rather easier to treat the diffraction problem and many analytical techniques, including rigorous Mathieu function expansion in the elliptic cylinder coordinate system, are applicable. However, if the slit has a finite thickness, it will be more difficult to solve the problem. From a view point of practical applications, it would be very interesting to see the effect of the thickness of the slit.

In this paper, we shall discuss about plane wave diffraction by a wide and thick slit. Based on the assumption that the slit's aperture a and thickness b are pretty large (i.e. $ka, kb \gg 1$), method used here is the high frequency asymptotic ray technique. For the geometry where the two half planes are located in $x-y$ plane, observation location may be classified into three regions:
A) illuminated region ($z>0$),
B) waveguide region ($-b<z<0, -a/2<x<a/2$),
C) transmitted region($z<-b$).
In each region, the scattered field should be constructed in a proper manner, such that the numerical evaluation is efficient. For region A, dominant scattered field consists of primary diffraction fields from each edges of the aperture, and if any, reflected plane waves. Also needed are re-radiation fields from the aperture, which account for the effect of slit's thickness, and are the *only* contribution to the transmitted region C. For region B, in addition to infinite number of multi-bouncing diffracted rays, a part of the incident wave directly enters here. This situation makes the ray summation formula cumbersome. Then, it may be useful to convert the ray summation into the corresponding parallel plane waveguide modal summation. Such conversion technique may be established by Poisson summation formula which has been successfully applied to various problems. Thus derived formula has been applied to compute the scattered field, and these result will be presented.

ANALYSIS OF A FREQUENCY SELECTIVE SURFACE HAVING A HONEYCOMB SUPPORT - A SCATTERING MATRIX APPROACH

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Roy E. Jorgenson
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Frequency Selective Surfaces (FSSs) are used as dichroic subreflectors for large reflector antennas and as antenna radomes on aircraft. Due to the high strength-to-weight ratio requirement for these applications, FSSs are usually backed by a layer of honeycomb which provides a strong yet lightweight support. Accurate characterization of an FSS along with its honeycomb support is important for the successful design of these dichroic surfaces and antenna radomes.

In the literature, analysis of FSSs having a honeycomb support is performed by replacing the honeycomb with an equivalent dielectric layer. A systematic study to validate this approach for impinging plane waves with different incidence angles and polarizations has not yet been reported. This paper presents an analysis of an FSS backed by honeycomb based on the scattering matrix approach. In order to use this approach, the periodicity of the FSS is assumed to be an integral multiple of that of the honeycomb. This analysis is carried out in two stages as summarized below.

First, the scattering matrices for the FSS and the honeycomb are generated separately. The honeycomb scattering matrix must be generated several times in order to map it to a matrix that corresponds to the perioidicity of the FSS. This new matrix is then cascaded with the FSS scattering matrix. Representative results of the spectral response of the composite FSS and honeycomb structure will be presented. These results will be compared to those calculated using the equivalent dielectric model.

APPLICATION OF ILDC 'S FOR CALCULATING THE RCS OF POLYHEDRIC STRUCTURES

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Incremental length diffraction coefficient (ILDC) or equivalent current (MEC) formulations obtained from the rigorous solution of the canonical wedge problem, provide an effective tool for predicting the RCS of complex structures.

Recently, an ILDC solution for an impedance wedge has been derived, which is applicable to Sommerfeld spectral integral representations of the scattered field [G. Pelosi et al., AP-S/URSI Symposium, 1988]. So far its pratical applicability is restricted to those cases where such a representation is available.

In this paper, this ILDC solution is employed to calculate the RCS of polyhedric structures. It allows us both to investigate into the usefulness of the solution and to give a physical interpretation of the various scattering mechanisms that may be excited at the edge of a wedge. Several numerical experiments have been performed in order to provide
a) an estimate of the importance of the fringe and surface wave contributions for various wedge angles and impedances;
b) an analysis of whether and where higher order contribution are required;
c) an inspection of the implications related to the numerical implementation of the algorithms.
To this end, numerical results obtained from applications to simply shaped, test structures, are presented. Also, the accuracy of the method is discussed and the effect of partial thin coatings is emphasized.

SPECTRAL GTD-FFT COMPUTATION OF FOCUSSED REFLECTOR FIELDS

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It is well known that the use of GO and GTD methods for the computational analysis of focal region fields is obstructed by a confluence of caustics and shadow boundaries which occurs near the focus. GO caustics arise from confluent stationary phase points of the PO integration over the reflector surface, and GTD caustics arise from similar degeneracies in the PTD edge-current integrals. Apart from the asymptotic field nonuniformities implied by these singularities, the occurrence of multiple nearby stationary points renders ray tracing difficult.

These problems do not occur if the diffraction problem is formulated in the spectral domain, rather than in the configuration space domain as is conventionally the case. In spectral domain GO one seeks those rays propagating in a given direction, rather than those passing through a given point. For the reflector problems we are addressing here, only <u>one</u> GO ray, and only <u>two</u> GTD rays which cannot degenerate, emerge from a focussing reflector with a plane-convex aperture. The stationary phase points corresponding to these rays can be found analytically for a paraboloidal reflector surface in offset-focus configuration. These facts permit a simple construction of the plane wave spectrum of the focussed field by means of a uniform GO/GTD treatment without caustics. The configuration space focal region field can be reconstructed from the spectral domain by the FFT alogorithm. All the spectral domain calculations can be carried out analytically in closed form, including Fresnel integral transition functions for the spectral domain shadow boundary, formed by the set of directions of those diffracted rays which are degenerate with reflected rays.

This method, when implemented numerically , provides a very efficient means of calculating focal- region fields. The rate- determining step is the FFT, which samples the focal region field at one point per diffraction lobe. Only one FFT is required to span a region in the focal plane, and the accuracy is asymptotically consistent with Keller's formulation of GTD, limited principally by aliasing errors in the FFT. The method successfully eliminates all the problems encountered in configuration space GO/GTD, while retaining the essential simplicity of these geometrical techniques.

ANALYTIC SURFACE-RAY TRACING ON A GENERAL HYPERBOLOID OF REVOLUTION FOR THE UTD APPLICATIONS

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In this paper; the integral ray-geometric parameters for the general hyperboloid of revolution (GHOR) have been presented for the first time for application to the high-frequency ray-theoretic formulations like the UTD (Pathak et al, IEEE Trans. **AP-29**, 911-922, 1981). This 3-dimensional derivation has been possible due to the successful application of the Geodesic Constant Method (GCM) developed by these authors (Jha et al, IEEE A-P Symp., 207-210, 1989).

In this method we establish that the Prolate-spheroidal Coordinate System is a Geodesic Coordinate (u,v) System so that a simplified expression for the geodesic differential equation of the first order can be readily obtained. As a subsequent step the metric of the arc length is integrated to get the arc length s(u) as a function of the incomplete elliptic integral of the second kind E(x,k)

$$s(u) = c\, E\left(\frac{a \cosh u}{(a^2+h^2)^{1/2}}, \frac{(a^2+c^2)^{1/2}(a^2+h^2)^{1/2}}{ac}\right) \qquad (1)$$

where 'a' and 'c' are the shaping parameters of the GHOR. Similarly, the generalized Fock parameter has been derived in terms of the incomplete elliptic integral of the first kind, F(x,k), as

$$\xi(u) = \frac{k_4}{a^2 c}\, F\left(\frac{a \cosh u}{(a^2+h^2)^{1/2}}, \frac{(a^2+c^2)^{1/2}(a^2+h^2)^{1/2}}{ac}\right) \qquad (2)$$

where $k_4 = \mathcal{K}^{1/3} c^{2/3} (a^4+a^2h^2+c^2h^2)^{2/3}$

Once these parameters have been obtained the surface ray fields can be readily computed by using Pathak's UTD formulations. Finally, these rigorous results along with the earlier published results (Jha et al, IEEE A-P Symp., 207-210, 1989) form the complete set of ray parameters for the entire set of quadric surfaces of revolution.

A GEODESIC CONSTANT METHOD FOR THE DETERMINATION OF SURFACE RAY GEOMETRIC PARAMETERS FOR AN ELLIPSOID OF REVOLUTION

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Although the ray-theoretic methods like the UTD (Pathak et al, IEEE Trans. **AP-29**, 911-922, 1981) are valid for convex surfaces in general, actual calculations have been presented mostly over the developable surfaces only. In particular, the radiators (antennas) on the ellipsoid of revolution are taken on the equatorial axis and the surface-ray paths are assumed to be confined to the principal directions thereby reducing it to the special case of a 2-dimensional ray analysis.

In contrast, a rigorous analysis for the surface-ray tracing on an ellipsoid of revolution in 3-dimensions based on the Geodesic Constant Method (GCM) is presented here. This differential geometry analysis in the Geodesic Coordinate System readily yields all the required ray parameters (except the integral types) in the closed form. In the case of the integral-ray parameters, viz. the arc length s(u) and the generalized Fock parameter $\xi(u)$, suitable substitutions reduce them to the incomplete elliptic integrals of the second and first kind, denoted respectively by E(x,k) and F(x,k).

$$s(u) = -cE\left(\frac{a\cos u}{(a^2-h^2)^{1/2}}, \frac{(c^2-a^2)^{1/2}(a^2-h^2)^{1/2}}{ac}\right) \qquad (1)$$

$$\xi(u) = \frac{-\chi^{1/3}\,(a^4-a^2h^2+c^2h^2)^{2/3}}{a\,c^{1/3}}\,F\left(\frac{a\cos u}{(a^2-h^2)^{1/2}}, \frac{(c^2-a^2)^{1/2}(a^2-h^2)^{1/2}}{ac}\right) \qquad (2)$$

The expressions derived here follow from the parametric equations expressed in the Geodesic Coordinate System (Jha et al, IEEE A-P Symp., 203-206, 1989). The ray parameters derived by the above method can be readily substituted in the UTD formulations to obtain the mutual coupling for arbitrarily located antennas on the surface of the ellipsoid of revolution. This 3-dimensional ray geometric analysis can be extended to the radiation problems as well.

Thursday AM

Joint AP-S, URSI-B Session 76

Polarimetric Probing of Distributed Media

Chairs: D. S. Zrnic, National Severe Storms Laboratory; A. B. Shupyatski, Main Geophysical Observatory

Room: W-110 *Time*: 8:15-12:00

8:20	**Cloud and Precipitation Investigations by Polarization Diversity Radars in the USSR** D. B. Kanareikin, S. Y. Matrosov, A. Melnik, Main Gecphysical Observatory; A. V. Ryzhkov*, Main Geophysical Ovservatory; G. G. Shchukin, A. B. Shupyatski, V. D. Stepanenko, V. K. Zaviruha, Main Geophysical Observatory	368
8:40	**Optimal Polarization Processing of Radio Signals for Remote Sensing Theory and Experimental Results** A. I. Logvin*, A. I. Kozlov, Moscow Civil Aviation Engineering Inst.	AP-S
9:00	**Doppler-Polarimetric Radar Research of Precipitation** H.W. J. Russchenberg*, Delft University of Technology	AP-S
9:20	**Polarimetric Signatures of Hydrometeors** D. S. Zrnic*, National Severe Storms Laboratory	369
9:40	**The Effects of the Target Motion on the Muller Matrix** Yasuo Kuga, Adib Nashashibi*, Adam Zysnarski, The University of Michigan	370
10:00	**Coffee Break**	
10:20	**Angular Glint in Polarization Agility Systems** R. V. Ostrovityanov*, Institute of Aviation Instrument Making	AP-S
10:40	**Angular Glint in Polarization Double-Channel Systems** A. A. Monakov*, Institute of Aviation Instrument Making	AP-S
11:00	**Backscattering Enhancement of Large Random Discrete Scatterers of Multiple Sizes and Polarimetric Dependence** Charles E. Mandt*, Leung Tsang, Akira Ishimaru, University of Washington	371
11:20	**Determining Anisotripic Properties of Ice by the Polarization Passive Microwave** A. I. Logvin*, A. I. Kozlov, Moscow Civil Aviation Engineering Inst.	372
11:40	**Dynamical Properties of Microwaves Scattering Matrix in Radar Polarimetry of Sea Surface** Boris S. Lande*, NW Correspondence Polytechnic Institute	AP-S

CLOUD AND PRECIPITATION INVESTIGATIONS BY POLARIZATION DIVERSITY RADARS IN THE USSR

D. B. Kanareikin, S. Yu. Matrosov, Yu. A. Melnik, A. V. Ryzhkov *
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In this report a brief review of investigations of clouds and precipitation held in the USSR by means of polarization diversity radars is presented. The first Soviet works in the field of radar polarimetry in meteorology dealt with problems of identification of hail zones in Cb clouds. As a result, some simple criteria were obtained for hail detection. These were based on joint measurements of radar reflectivity and linear depolarization ratio (LDR). Appropriate polarimetric devices attached to conventional meteorological radars were designed. At the present time special attention is devoted to investigations of hydrometeors by measuring differential reflectivity (ZDR) and joint LDR and ZDR measurements. These research works are carried out by means of an automatic radar polarimetric system operating in X-band. A lot of experiment data were obtained concerning vertical structure of ZDR distributions in clouds and precipitation. It was shown that different hydrometeor types can be classified by their ZDR signatures. It is obvious also that joint ZDR and LDR measurements afford remove ambiguities in the interpretation of conventional radar data.

One of the nontraditional approaches in radar polarimetrics is Mueller matrix elements and anisotropy parameters estimation for meteorology targets. Mueller matrix elements evaluation is based on the measurement of the reflected power while radar antenna polarization is being changed. Either a phase plate or a polarization grid can be used as a polarizer for such a change. The anisotropy parameter is defined as a ratio of radar reflectivities on linear and circular polarizations. Aforementioned approaches provide an opportunity to gain new information about hydrometeors.

Some theoretical results are also presented in the report. They concern classification of meteorological targets in terms of invariant polarization parameters. Such a consideration allows possibilities for polarization selection of hydrometeors by graphical interpretation on the Poincare sphere. Co-poll and cross-poll nulls zones for different meteorological targets are represented on this sphere. Some results of theoretical modelling of various polarization parameters for different hydrometeor types are also considered in the report.

POLARIMETRIC SIGNATURES OF HYDROMETEORS

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Radars that switch between linear orthogonal polarization provide estimates of the reflectivity factor at horizontal polarization Z_H, the differential reflectivity factor Z_{DR}, the differential propagation constant K_{DP}, and the correlation coefficient between horizontally and vertically polarized echoes $\rho_{HV}(0)$. A decision rule that partitions the four dimensional space of these variables is sought such that each partition corresponds to an identifiable hydrometeor population. The problem is complicated because polarimetric signatures of hydrometeors are not unique. Nevertheless some success has been achieved in detecting regions of mixed phase hydrometeors, hail and pure rain. Improved quantification of rainfall is possible and even discrimination of large hail seems to be probable. Theory suggests that needle like ice crystals should also have discernible signatures. Examples of some data from convective storms in Oklahoma will be shown to corroborate theoretical predictions.

THE EFFECTS OF THE TARGET MOTION ON THE MULLER MATRIX

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To obtain the Muller matrix of the target, the usual technique is measuring the scattering matrix by a coherent polarimetric radar and calculating the Muller matrix by taking the correlation of different elements in the scattering matrix. In this case the radar transmits V (vertical polarization) and receives V and H (horizontal polarization). Then it transmits H and receives V and H. Because V and H polarizations are sequentially transmitted, the components of the scattering matrix are not acquired simultaneously. If the target is stationary, the sequential data acquisition does not cause any problems for calculating the Muller matrix. However, if the target is moving, the Muller matrix obtained from the scattering matrix measurement may not be correct because some components of the Muller matrix are defined as the average of the correlation between V and H components. The correlation of V and H components measured at different time is not same as the correlation of V and H measured at the same time.

In this paper we will present the experimental studies of the effects of the target motion on the Muller matrix. We used a vector network analyzer based radar system for obtaining the scattering matrix in wide-band frequency range. Our results show that the first 4 components, $|f_{vv}|^2$, $|f_{hv}|^2$,$|f_{vh}|^2$, and $|f_{hh}|^2$, do not depend on the target motion as expected. However, the terms representing the correlation between V and H polarizations are significantly different between the stationary and moving targets.

BACKSCATTERING ENHANCEMENT OF LARGE RANDOM DISCRETE SCATTERERS OF MULTIPLE SIZES AND POLARIMETRIC DEPENDENCE

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Abstract

Backscattering enhancement has been previously observed for a random medium containing a sparse distribution of scatterers of very large size. It was found that the depolarized return contains an enhancement that is unobscured by single Mie scattering and cannot be accounted for by transport theory.

A second order theory based on identical scatterers was previously used to account for the observed enhancement. The theory is obtained by summing the first and second order ladder terms and the second order cyclical term of the Bethe-Salpeter equation. The cyclical term is included since this contributes directly to the backscattering enhancement not accounted for in the ladder approximation which is consistent with the transport theory. Mie scattering is used to compute both the copolarized and depolarized return and gives reasonable agreement with experimental data. However, the copolarized return contains rapid fluctuations with angle that is characteristic of Mie scattering for particles of identical size. However in the experiment, the particles follow a size distribution. Recently we have made calculations of the copolarized and depolarized return and have included a size distribution. As a result, the fluctuations have generally disappeared. Good comparison with experimental data is obtained for both returns from a slab medium containing a sparse distribution of dielectric spheres with average ka of 298 and optical thickness of 2.

We have also computed the Mueller matrix elements for the same case. Using second order multiple scattering with the effects of size distribution included, the Mueller matrix elements for the ladder and cyclical terms are derived and summed. This model is used to investigate the effects different incident wave polarization states have on the backscattering enhancement. Calculated data is shown for linear, circular, and elliptically polarized plane waves incident on a slab medium containing a sparse distribution of large discrete scatterers.

DETERMINING ANISOTRIPIC PROPERTIES OF ICE BY THE POLARIZATION PASSIVE MICROWAVE

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Moscow Civil Engineering Aviation Institute

In studying sea and mainland ice problems arise which are connected with determining its structure physical, mechanical and chemical properties. One of the essential ice characteristics is its anisotropy as a geophysical characteristic of an object. Polarization characteristics of ice microwave radiation make it possible to determine its anisotropic properties. Studying the changes in microwave radiation brightness temperatures at different polarizations (vertical and horizontal) at different visual angles has the possibility of determining the essential ice anisotropic properties, the ways of building ice dielectric permitivity tensors being considered. Ice sounding experiments by active radar methods confirmed the tensor character of dialectric permitivity in Antarctics shelf ice and on some types of sea ice. That's why the use of polarization measurements of ice microwave radiation provides another technique for increasing the correctness of the data obtained. The study gives the main correlations connecting the values of different brightness temperatures in horizontally and vertically polarization components of microwave radiation with the values characterizing the object anisotropy. In this case the concept "polarization anisotropy" is applied which is concidered within the framework of varions models, describing object anisotropic state (ice in particular). It should be indicated that the problem is considered both in terms of deterministic and statistic methods. In certain conditions the results obtained can be applied not only to ice surfaces but to any other geophysical objects with anisotropic properties as well. Within the framework of the problem of ice anisotropic properties being solved one more application of radiopolarimetic analysis can be mentioned. Through the analysis of the polarization structure of ice proper radiation it is possible to determine the strained state of an ice object. In other words, it is possible to show the directions of C-axis orientation in ice, to answer the question whether the ice object under investigation is in a strained state. Unfortunately so far we have failed to receive quantitative estimations by radiometry methods.

Thursday PM
URSI-B Session 77
PDE Method

Chairs: Michael A. Morgan, Naval Postgraduate School; R. W. Ziolkowski, Lawrence Livermore National Laboratory

Room: W-107 *Time*: 1:15-5:00

NUMERICAL ERROR IN THE FINITE ELEMENT TREATMENT OF THE OPEN-REGION HELMHOLTZ EQUATION

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The direct numerical solution of the Helmholtz equation is a promising alternative to conventional integral equation formulations for electromagnetic scattering from highly heterogeneous bodies. The differential equation is augmented with some form of absorbing boundary condition in order to model open regions, and discretized using the finite element method. For a variety of electrically small test cases, the accuracy of the approach appears comparable to integral equation formulations (Peterson, *Journal of Electromagnetic Waves and Applications*, vol. 3, pp. 87-106, 1989;. Peterson and Castillo, *IEEE Trans. Antennas Propagat.*, vol AP-37, pp. 601-607, May 1989.) Errors that have been observed in the numerical results are often attributed to the use of approximate local absorbing boundary conditions.

Recent research suggests that errors observed in the solution may not originate with the absorbing boundary condition, but with the process of discretizing the differential equation itself. A systematic study of these errors was attempted using a one-dimensional equation representing the electromagnetic scattering from a dielectric slab. Results will be presented that clearly indicate a progressive phase error in the solution that grows in proportion to the size of the problem domain. This error is observed for both total-field formulations and scattered-field formulations, and appears to be independent of the absorbing boundary condition. Although the error can be reduced by decreasing the cell sizes in use or employing smoother basis and testing functions within the finite element discretization, its presence may place a practical upper limit on the electrical size of the problem domain.

PLANE WAVE SCATTERING FROM MATERIAL CYLINDERS AT OBLIQUE INCIDENCE USING THE BYMOMENT METHOD

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This paper deals with the problem of electromagnetic wave scattering of plane waves from infinite cylindrical structures in a homogeneous medium at oblique incidence. The axis of the cylinder is taken parallel to the z-axis in a cartesian coordinate system. The cross-section of the cylinder can be of any shape, while its material composition is also arbitrary, with dielectric permittivity ϵ, magnetic permeability μ, and electric conductivity σ being arbitrary functions of (x, y).

With the field variation along z defined by the incident field according to $\exp(-\Gamma z)$, it is well-known that the problem can be formulated in terms of the z-components of the electric and magnetic fields. For the finite-element solution of the problem, the material properties are assumed constant within each element, thus $(\nabla_{xy}^2 - u^2)E_z = 0$ and $(\nabla_{xy}^2 - u^2)H_z = 0$ within each element, where $u^2 = j\mu\omega(\sigma + j\epsilon\omega) - \Gamma^2$. The method of weighted residuals is used to formulate the finite-element expressions. The boundary conditions along material interfaces are then incorporated properly in the resulting weak formulations of the above equations for E_z and H_z, thus producing the final coupled weighted-residual statement of the problem.

The finite-element solution is performed using the bymoment method (A. Cangellaris and R. Lee, 1989 IEEE AP-S International Symposium Proceedings, 1116-1119). This method, uses an artificial conforming surface to decouple the scatterer from the exterior homogeneous region. The solution in the interior is generated solving a standard Dirichlet boundary-value problem, and it is coupled to the exterior by an elegant use of Green's theorem in the exterior region. Numerical results will be presented for the case of various geometries, along with comparisons with series solution results for the case of a circular cylinder (J.R. Wait, Can. J. Phys. 33, 383-390, 1955) that demonstrate the validity of the formulation and the associated computer program.

FINITE ELEMENT SOLUTION OF ELECTROMAGNETIC SCATTERING BY A BODY OF REVOLUTION USING AN ASYMPTOTIC BOUNDARY CONDITION ON A CYLINDRICAL OUTER BOUNDARY

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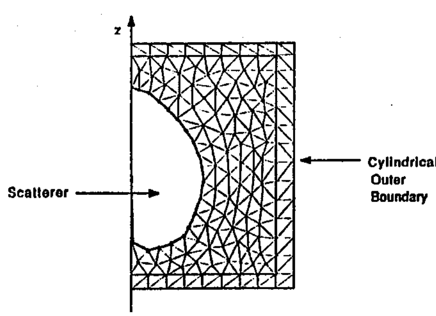
In two recent papers (R. Gordon & R. Mittra, 1989 URSI Digest; R. Mittra & R. Gordon, IEEE T-AP, June, 1989) we have presented a finite difference technique for solving the problem of electromagnetic scattering by a p.e.c. body of revolution(BOR). In order to more accurately model bodies having irregular cross-sections, to more easily handle problems in which inhomogeneities are present, and to eliminate the inaccuracies arising from taking numerical derivatives, we have now developed a finite element program for solving this same problem. The potentials we use are the coupled azimuthal potentials (CAPs) introduced by Morgan and Mei for the inhomogeneous BOR problem. These potentials satisfy a pair of coupled partial differential equations. We show how the weak form of these equations can be used to develop a finite element formulation of the problem without the use of a variational expression. We also show how a cylindrical outer boundary can be used to truncate the finite element mesh. For long, slender scatterers, the use of a cylindrical rather than a spherical outer boundary can significantly reduce the number of unknowns needed. The Bayliss-Turkel (B-T) type of absorbing boundary condition, typically used for FEM mesh truncation at the outer boundary, does not lend itself to generalization to the potentials used in this problem. Instead, an asymptotic boundary condition obtained from Wilcox's expansion for the scattered field in terms of powers of r^{-1} is shown to be very convenient for the mesh truncation problem for the CAPs.

An important feature of this approach to solving the FEM problem using an absorbing boundary condition is that it enables one to derive a good approximate solution to the scattering problem in just one step. In contrast, the Unimoment method involves a two-step procedure, which not only requires repeated solution of the p.d.e. but the inversion of a full matrix as well. Numerical results are presented for some representative problems and are compared with analytical solutions as well as with those obtained from a Method of Moments approach. The comparisons are found to be quite favorable.



A COMPARISON OF ISOPARAMETRIC EDGE ELEMENTS AND DNET ELEMENTS FOR 3D ELECTROMAGNETIC SCATTERING PROBLEMS

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Two novel types of three-dimensional isoparametric finite elements are introduced for computing two and three dimensional vector basis functions which are compatible with 3D electromagnetic scattering problems. Isoparametric edge elements are conformable to curved surfaces, and have degrees of freedom which correspond to the tangential field along the lattice edge. In a quadratic element of this type, the tangential field varies quadratically along the edge interpolating the values at three nodal points on the edge. While the resulting fields from this quadratic element scheme are not divergenceless, the solutions are nonetheless highly accurate. Tangential continuity of fields are maintained across element boundaries, while normal components of fields are discontinuous.

The DnEt element is node-based, with 3 degrees of freedom per node. At non-boundary nodes, these degrees of freedom represent the x,y,z components of the field. The degrees of freedom for nodes at material boundaries represent the field components in a rotated coordinate system, with the component normal to the boundary scaled to correspond to the flux density rather than the field. For electric fields, the degrees of freedom at a boundary node represent the D normal component and the two E tangential components, hence the name DnEt. Both these new elements thus treat boundaries of dielectrics, permeable materials, and conductors in such a way that the appropriate field jump conditions are maintained automatically. For edge elements continuity of normal D holds in a Galerkin sense.

Our implementation schemes follow directly from the weak form of the vector Helmholtz equation, and thus correctly model the general cases of anisotropic and non-uniform materials. An absorbing boundary condition is compatible with each of the element types. Scattered field results for implementations of each element type illustrate qualitative agreement of the two finite element method results with analytic solutions. Both methods lend themselves to implementation on distributed computing systems. We discuss the relative merits of each method in terms of accuracy, computational complexity, and ease of parallel implementation.

USE OF DIVERGENCELESS BASIS FUNCTIONS IN FINITE ELEMENTS FOR ELECTROMAGNETIC SCATTERING PROBLEMS

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The use of divergenceless vector basis functions in finite element solution of Maxwell's equations is examined. These vector basis functions are defined within a triangle (2-D) or a tetrahedron (3-D). They are associated with each of the edges of the triangle or tetrahedron rather than the nodes. The continuity of the tangential component of the vector field is exact while the continuity of the flux is approximate. Use of these type of basis in finite elements solving Maxwell's equations do not seem to contain any parasite solution or "spurious mode" as the scalar basise do.

To examine the field behavior on the dielectric interfaces, we first solve a boundary value problem, that is, to find the electric field inside a finite region for a given tangential magnetic field on its most outer boundary. We then use these vector basis functions in the hybrid finite element and moment method to solve the scattering problems due to inhomogeneous dielectric objects (2-D and 3-D). In both cases, we found the numerical solution agrees well with the exact solution when it is available. The discontinuities in the normal component of the electric field on the dielectric interface are approximated reasonably well. However, as the dielectric contrast increases, the mesh has to be well resolved to approximate the field well.

FINITE ELEMENT MODELING OF LOW FREQUENCY SCATTERING IN SEAWATER

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Three dimensional electromagnetic scattering has been widely used as a remote sensing technique for many years. Recently there has been a great deal of attention focused on the application of numerical methods to the modeling of electromagnetic scattering in both two and three dimensions. Of particular interest is the ability to utilize numerical methods to solve scattering problems which are difficult to solve by other means. One area of interest has been the solution of electromagnetic scattering problems in conductive media such as seawater. Generally problems of this type are low frequency in nature and occur in an unbounded region.

Finite elements offer a convenient means of dealing with the complex geometries encountered in this type of scattering problems. However, scattering in unbounded regions is generally difficult to model using finite elements. The author of this paper recently reported the results of studies which demonstrated the feasability of modeling low frequency scattering problems in conductive media via the unimoment method. At the time the study had been limited to electrically small scattering objects. That work has since been extended to include scattering objects which are on the order of a wavelength or larger in size. This paper will report the results of these studies as well as studies to determine the effects of mesh size on the accuracy of the algorithm.

FD COMPUTATION IN ANISOTROPIC MEDIA USING UNCONSTRAINED MESHES – OBLIQUE INCIDENCE ON 2-D SCATTERERS

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We present a novel algorithm to compute the field in the vicinity of anisotropic media, using Finite Differences (FD) applied to grid points on an unconstrained triangular mesh. The material boundaries are prescribed in x-y only, independent of z. The permittivity and permeability are general tensors, with non-zero xy and yx elements, and with each element also independent of z. The ability to analyze obliquely incident waves with arbitrary polarization gives the proposed method an advantage over previously reported techniques of computing the fields in the presence of anisotropy. Generalizing the procedure to three dimensional geometries uses the same concepts, but is of course more tedious.

Finite Difference EM field computation in either time or frequency domain (FD-TD, FD-FD) is clearly a promising means of theoretically simulating wave interaction with complex objects. Although recent improvements in computational power have made problems with a great many grid points tractable, it is still essential to have methods that are as efficient and accurate as possible. Thus unconstrained meshes, with varying triangular element sizes and shapes which closely fit the curves and edges of real objects are preferable to rectangular meshes. However, complications arise in non-cubical meshes when components of field contribute to orthogonal components of flux.

The novel method uses the integral forms of the Faraday and Ampere laws on complementary, interlocking Dirichlet/Delaunay grids to find the fields tangential to one grid from flux values tangential to the other. Anisotropy is considered by first finding the complete vector flux at each grid point from the flux along each segment leading to that vertex; and then averaging adjacent vertex flux vectors and inverting to give the field component along each grid segment. This averaging provides the correct segment tangential field even though the Maxwell equations provide only the segment tangential flux (which is not simply proportional to the field in anisotropic media).

Capability to theoretically predict anisotropic scattering efficiently is an important but difficult problem. This method helps make it more tenable.

A FINITE INTEGRAL TECHNIQUE APPLIED TO TRIANGULAR SUBDOMAINS REPRESENTING AN INFINITE CYLINDER OR ROTATIONALLY SYMMETRIC BODY

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Maxwell's equations in integral form are applied directly to a flat triangular mesh using simple sub-domain basis functions to represent the fields. A system of matrix equations is thus obtained which represents a discrete approximation to Maxwell's equations. The magnetic field quantities may be eliminated among the equations to obtain a discrete approximation to the Helmholtz equation which also reduces the total number of unknowns. Two formulations are used, one in which the mesh represents the cross section of a waveguide, and the other, a longitudinal cross section of a body of revolution. Advantages of the triangular mesh formulation are that irregular boundaries may be accommodated easily and the density of triangles/unknowns can easily be increased in regions of rapid field variation. The approach reported also has the advantage that the fields are defined at all points interior to triangles and hence complex interpolation schemes and severely restricted triangle shapes are not required. To date only regions bounded by conductors have been modeled; however, it is anticipated that various boundary termination approaches can be straightforwardly implemented for treating exterior problems.

The formulation has been validated by determining cutoff frequencies of certain cylindrical waveguides and the resonant frequencies of rotationally symmetric cavities. Inhomogeneously filled cases and several mesh schemes have been examined. Cutoff frequencies of rectangular and circular waveguide modes are found to agree well with analytic results, even for relatively coarse meshes. Comparisons with computed and measured results have also been made for inhomogeneously filled cavities.

A MODIFIED TRANSVERSE ELECTRIC FIELD FINITE-ELEMENT FORMULATION FOR DETERMINING THE PROPAGATION CHARACTERISTICS OF ENCLOSED PLANAR MICROSTRIP GEOMETRIES

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This paper presents a method for determining the propagation characteristics of guided waves in uniform cylindrical waveguides of arbitrary cross-sections. The boundary condition on the wall of the guide is given in terms of an equivalent surface impedance. The method is based on a weighted-residual formulation of the vector wave equation for the electric field transverse to the axis of the cylinder. The finite-element method is used to select the expansion and weighting functions. The resulting matrix eigenvalue problem is in the form of a generalized eigenvalue equation.

Currently we are interested in applying the method to rectangular cross-sections. For example, the method can be used to determine the shifts in the propagation constant for partially filled waveguides due to walls of finite conductivity.

To increase the numerical efficiency of the method, we have developed an alternate formulation for analyzing enclosed planar microstip structures. This method uses the above transverse electric field formulation for the regions around the microstrip and a weighted-residual formulation for properly chosen vector potentials in the remainder of the cross-section. To simplify the application of the tangential field continuity conditions along the dielectric interfaces as well as the boundary conditions at the conducting walls of the enclosure, the modes of the stucture without the microstrip present are used as entire domain expansion and testing functions in the vector potential formulation. The two formulations are coupled by satisfying the interface conditions at the artificial boundary used to separate the region surrounding the microstrip form the rest of the waveguide.

APPLICATION OF FD AND PCGM FOR FREQUENCY-DOMAIN SCATTERING PROBLEMS

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Good results can not be achieved by utilizing the method of moment to the solution of electrically large scattering problems or to that of complex scatterer in inhomogeneous medium as the limitation of computer storage and CPU time. In this paper, the frequency-domain finite-difference (FD) method with absorbing boundary condition and the proconditioned conjugate gradient method (PCGM) is applied to solve EM scattering problems. For the solution of the scattering field scattered by a perfect conducting body in various medium, we directly use the finite-difference method to solve frequency-domain wave differental equation. A absorbing boundary condition [1] is introduced at some distance from the scatterer in order to achieve a reflection-free truncation of a FD-FD lattice. The PCGM [2] is used to solve the large sparse matrix equation arising from the wave differental equation. Classical iterative methods may yield poor convergence rates when applied to large sparse of simultaneous equations. In our PCGM technique we formally carry out an incomplete choleski factorization of the coefficient matrix. During the factorization some off-diagonal coefficients is discarded and at the same time the magnitude of the corresponding diagonal elements is adjusted. Hence the convergence rate of CG iteration which is performed implicitly on the preconditioned matrix is greatly improved because of the eigenvalues being clustered around a small number of distinct values. In computer program one-dimension array is adpoted to store non-zero elements of the coefficient matrix and the factorizated coefficients. This makes the quantity of storage considerably reduced. Several numerical examples are performed by the technique mentioned above. The acceptable results predict this combination method is likely to be very promising.

REFERENCE

[1] S.I.Hariharan, "Absorbing boundary conditions for exterior problems", in Numerical Methods for Partial Differential Equations (S.I.Hariharan & T.H.Moulden,Ed.), 199-232,1986.

[2] M.A.Ajiz & A.Jennings,Int.j.numer.methods eng. Vol.20,949-966,1984.

This work is supported by NSNF of China.

Thursday PM1

Joint AP-S, URSI-B Session 80

Adaptive and Signal Processing Arrays III

Chairs: Henry S. Eilts, Texas Instruments Incorporated; R. B. Dybdal, The Aerospace Corporation

Room: W-117 *Time*: 1:15-3:00

1:20	**The Bandwidth Performance of Linear Adaptive Arrays with Tapped Delay-Line Processing** Frederick W. Vook*, R. T. Compton, Jr., The Ohio State University	AP-S
1:40	**Bandwidth Performance of Phased Array with Tapped-Delay Line Filter** Y. S. Kim*, Ira M. Weiss, The Aerospace Corporation	AP-S
2:00	**Adaptive Arrays for Multipath Fading Reduction** Seungwon Choi*, Sung H. Cho, Electronics & Telecom. Research Inst.; Tapan K. Sarkar, Syracuse University	386
2:20	**Design and Simulation of Superdirective Adaptive Antenna Arrays** M. M. Dawoud*, Y. L. Abdel-Magid, A. N. Ismail, King Fahd Univ. of Petroleum & Minerals	AP-S
2:40	**Real Phase-Only Nulling Algorithm (REPONA) for Pattern Synthesis** Yanchang Guo*, Jianxin Li, Nanjing Research Institute of Elec. Tech	AP-S

Adaptive Arrays for Multipath Fading Reduction

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This paper presents procedures of applying adaptive algorithms such as the method of Steepest Descent (M-SD) and the Conjugate Gradient method (CG-M) for solving ill-conditioned matrix equations which arise in multipath telecommunications.

Autocorrelation matrices and crosscorrelation vectors are computed based on the the assumption that ensemble averages of the signals are available. LMS method which uses the single time values rather than the average values is also considered and the performances are compared to that of M-SD and CG-M.

The algorithms considered in this paper do not require the matrix inversion to be computed. Therefore, the size of the matrix, which is determined by the number of antenna elements, can be arbitrarily set for enhancing the array performance. When the correlation matrices are to be computed, it is important to note that the mutipath components are correlated with one another and thermal noises exist at each antenna element. The more are the multipath components correlated with one another, the worse becomes the eigenvalue distribution of the matrix. This paper treats generalized mutipath problems in following two senses: First, matrices and vectors are computed for the different values of correlation factor thus the optimum weights are computed for each different case; Secondly, there is no restriction on the number of antenna elements so that the optimum weights can be computed regardless of the number of components in the input signals.

The performance of each adaptive algorithm is compared by utilizing the array weights obtained from each adaptive algorithm for forming the pattern nulls along the incident angle of interference components. CPU time for the convergence with a desired accuracy in each method is also compared and we conclude that CG-M can converge faster than the other methods considered in this paper.

Thursday PM1

URSI-B Session 85

Ray and Asymptotic Methods - II

Chairs: Robert T. Brown, Lockheed Aeronautical Systems Company; S. W. Lee, University of Illinois

Room: W-108 *Time*: 1:15-3:00

Nonspecular Nature of Physical Optics Scattering

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Until recently it was widely believed that bistatic scattering in the physical optics approximation always has a main lobe "centered on the specular direction," or the direction dictated by Snell's law for a planar surface. For example, the above statement is made by Knott *et al.* (*Radar Cross Section*, Norwood, Massachusetts:Artech House, 1985, pp. 121-122), accompanied by schematic illustrations of a main lobe in the specular direction for bistatic scattering from a flat plate. The assumption of specular bistatic scattering has been the basis for suggestions that one could combine physical optics with specular ray tracing in multiple scattering calculations.

However, it has been pointed out by Asvestas (*IEEE Trans. Antennas Propagat.* vol. AP-34, pp. 1459-60, 1986) that the specular assumption is valid in the physical optics (PO) approximation only for TE polarization, or scattering of radiation initially polarized with the electric field perpendicular to the plane defined by the normal to the scattering surface and the propagation vector of the incident radiation. In the work reported here the complete scattering matrix for bistatic PO scattering from an arbitrary planar surface has been examined. For the diagonal terms the direction of maximum scattering lies in the plane of incidence; for TE polarization (σ_{HH}) there are two maxima, one in the forward scatter direction and one in the specular direction; for TM polarization (σ_{VV}) the two maxima always lie between the outward normal and the specular direction, and between the inward normal and the forward scatter direction, respectively. Only in the limit of infinite target width do the maxima approach the forward and specular directions. For the off-diagonal, or cross polarization terms, the maxima can never lie in the plane of incidence, since the cross sections σ_{VH} and σ_{HV} always vanish in this plane. The pattern for these cases is split into lobes located in pairs about the plane of incidence and skewed away from the specular or forward directions toward the $\phi_s = \pi/2$, $3\pi/2$ plane.

CURRENTS ON A CONE WITH ROUNDED EDGE AT HIGH FREQUENCIES FOR ON AXIS ILLUMINATION

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33114 - LE BARP FRANCE

A cone with rounded edge, illuminated by an on axis plane wave, is computed using an electric field integral equation axisymetric code at several frequencies. The total length of the cone is about 30 wavelengths at the highest frequency.

The currents are then computed asymptotically using.

- physical optic plus travelling wave diffracted by the cone (Trott - PHD Thesis - OSU), plus small perturbation currents due to the discontinuity in curvatuve diffraction and creeping rays, on the illuminated part.

- Fock functions with ray convergence on the curved part in the shadow and light shadow transition zone .

- a combination of Fresnel and Fock functions on the flat base in the penumbra.

- modified sphere solution near the axial caustic of creeping rays in the penumbra.

The agreement between the two solutions is everywhere within 10 %.

Some applications of the results for hybrid asymptotic/method of moment techniques are discussed.

PREDICTION OF BISTATIC SCATTERING FROM PERFECTLY CONDUCTING FLAT PLATES BY THE METHOD OF EQUIVALENT EDGE CURRENTS

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Within the latest four decades the method of equivalent edge currents (EEC's) has been treated in regard to both derivation and application by several authors. This is true for all three distinct types of EEC's: GTDEEC's, POEEC's, and PTDEEC's which yield approximations to the total, the physical optics part, and the fringe wave part of the scattered field, respectively. A number of different EEC expressions causing discrepant values for the calculated field consequently exist. For GTDEEC's the result is obviously erroneous. A comparison of the different expressions is made possible by bringing these on a common form.

A new derivation leading to a general set of EEC's is carried out. The applied procedure resembles that of [A. Michaeli, Trans. AP, Vol. AP-32, No. 3, 1984, pp. 252-258] but differs in two important aspects. First, the half plane solution is employed directly; second, the direction of the incremental strip is not restricted to be perpendicular to the edge and it thus appears parametrically in the final expressions. It is found that the previously reported expressions can be retrieved by assigning different values to this parameter. Furthermore, the cause of the gross error in GTDEEC's is understood by observing the effect of the incremental strip direction.

By appropriately directing the incremental strip it is found that the POEEC's will recover the PO field exactly. The proper direction depends on the projections of the directions of incidence and observation onto the plane of the plate. For PTDEEC's the incremental strip is directed along the Keller cone. An optimum set of EEC's is then obtained by adding POEEC's and PTDEEC's based on different directions of the incremental strips.

The half plane EEC's do not account for edge interaction effects occurring on the actual scatterer. A refinement based on truncation of the incremental strip is therefore obtained. Both the direction and the length of the incremental strip will thus appear parametrically in the new EEC expressions.

Numerical results for the disc and the square plate are presented and compared to an exact and a moment method solution, respectively.

Adiabatic and Intrinsic Modes for Propagation in Longitudinally Inhomogeneous Guiding Environments

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and

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Abstract

Electromagnetic wave propagation in waveguides or ducts with inhomogeneous properties along the propagation direction is becoming increasingly important for applications in natural environments, such as the earth's troposphere, and in man-made devices such as tapered couplers, graded index components, and horn antennas. In general, analytical modeling for this class of problems requires coupling between the modes that would exist in the locally homogeneous surroundings. When the longitudinal variation is gradual over relevant wavelength scales, lowest order mode coupling can be accounted for by local (adiabatic) modes which adapt continuously, without coupling to other adiabatic modes (AM), to the slowly changing conditions. However, the AM formulation fails in cutoff regions that are usually caused by narrowing duct dimensions; here an impinging trapped mode is either totally reflected, with evanescent decay beyond the cutoff zone, or converted into a radiating mode by leakage. To uniformize the AM formulation through the cutoff regions, it has been proposed to "flesh out" the sparse AM spectrum by a spectral continuum constructed from the AM field (J.M. Arnold and L.B. Felsen, Wave Motion 8, 1-14, 1986; J. Acoust. Soc. Am. 1990). This reconstructed continuum, referred to as an intrinsic mode (IM), can be reduced to the AM when legitimate but remains applicable in its nonreduced state where the AM fails.

The IM formulation is tested here on two canonical two-dimensional guiding environments which are separable in a curvilinear (cylindrical) coordinate frame but are parametrized in terms of locally adaptive AM. The first is a perfectly conducting homogeneous wedge waveguide. The second is a graded index waveguide whose refractive index varies like $n^2(\rho,\theta)=n_0^2-(\alpha\theta/\rho)^2$, where (ρ,θ) are cylindrical coordinates, while n_0 and α are constants; here, the AM are confined transversely between modal caustics which parametrize the AM as well as IM construction. The AM and IM formulations are reviewed and then applied to the two test geometries. In each case, it is shown that the properly parametrized IM can be transformed into the known exact modal solutions. Moreover, asymptotic reductions of the IM integral by saddle point techniques yield the compact AM away from cutoff points as well as compact uniform (Airy function) transitions across cutoff points. In an extensive set of numerical computations, numerical evaluation of the full IM integral is compared with the reduced asymptotic forms and also with the closed form known exact solutions. The results establish guide lines for subsequent applications where canonical reference solutions are unavailable.

SIMPLE ANALYTICAL SOLUTION TO ELECTROMAGNETIC SCATTERING BY A TWO DIMENSIONAL CONDUCTING OBJECT WITH EDGES AND CORNERS

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Simple and rigorous analytical solution is presented by invoking on-surface radiation condition theory (OSRC) for the analysis of electromagnetic scattering by a perfectly conducting two dimensional object. The scattering object is assumed to be placed in a free space medium and is excited by a time harmonic plane wave having either transverse magnetic (TM) or transverse electric (TE) polarization. The close form analytical result for the induced electric current distribution and the radar cross section is principally applicable to the case of a convex conducting object having arbitrary two dimensional cross section with arbitrary edges and corners.

Earlier, only the preliminary OSRC study is reported for the electromagnetic scattering by a two dimensional conducting circular cylinder, a thin strip and a square cylinder with TM polarization. Further, a differential equation solution is reported for the scattering by a circular cylinder with TE polarization. Some validation data are also reported for the induced surface current and the radar cross section. Specifically, in the OSRC study reported earlier for the strip scatterer and the square cylinder scatterer, the effect of the nonuniform electric currents at the geometric corners are completely excluded, but only the uniform currents are taken into account in the calculation of the radar cross section. In the present study, a rigorous boundary value analysis is reported to include the nonuniform electric currents at the corners so that arbitrary cross sectional convex geometries consisting of arbitrary edges and corners can be systematically analyzed. For the scattering geometries considered, it is also shown that the OSRC result for the induced electric current has a close correspondence to the electric currents of the physical theory of diffraction. Two canonical conducting scattering objects, such as, a triangular shaped scatterer and a thin strip scatterer are analyzed for the plane wave excitation to demonstrate applicability of the analytical results reported in this paper. Validation data for the induced surface electric current distribution and the monostatic radar cross section are also reported by comparing the OSRC data with respect to the numerical solution obtained by solving the electric field integral equation based on the method of moments technique.

Thursday PM

URSI-E Session 88

Polarization Vector Signal Processing, Electromagnetic Noise and Interference

Chairs: Frederick M. Tesche, Consultant; Itzhak Shapir, RAFAEL

Room: W-110 *Time*: 1:15-5:00

STUDY OF DPCA AND SPACE-TIME PROCESSING FOR AIRBORNE CLUTTER REDUCTION

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A model has been developed to describe the structure of target and clutter echos received on the elements of a moving radar array in both the space-time and Fourier domains. Using this model we will demonstrate how a space-time processor suppresses both fixed and moving clutter while tuning to a hypothesized target. DPCA (displaced phase center antenna) will be shown to be a special case resulting from suppressing the ground-frozen clutter. The eigenvector spectral decomposition of the clutter covariance matrix will then be used to develop insights into how clutter is suppressed, and the effects of random clutter motion, antenna phase and amplitude errors, velocity mismatch, etc., on the performance of the space-time processor.

GLINT NOISE CANCELLATION METHODS FOR AN OPEN LOOP, EXTENDED MONOPULSE, AUTOMOTIVE RADAR

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Monopulse radar shows promise for use as an anti-collision sensor. Normally, monopulse radars employ a beam sweep of 3 degrees or less. The Grimes have proposed a new type of extended monopulse entitled cradar. (D.M. Grimes and C.A. Grimes, IEEE Trans. Vehicular Technology, Feb. 1990.) The proposed system is an extended monopulse capable of an angular sweep of 17 degrees and a range of 100 meters.

The effects of glint noise can limit the tracking accuracy of monopulse radars. The problem is amplified when, as in automotive environment, targets cannot be considered point-like. In some cases, the point being tracked by radar can move out of the physical confines of the target.

Aperture averaging and frequency averaging are two possible methods used to mitigate the effects of glint noise. Both these methods were tested through computer simulation for the proposed horn antenna of the system. The analysis shows that aperture averaging alone is not enough to solve glint noise problems. Averaging over a range of frequencies centered about the proposed operating frequency shows that it can alleviate the glint noise problem for cradar.

SPREAD SPECTRUM CODING FOR VLF/ELF UNDERGROUND COMMUNICATION

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&
S. V. RAVIKUMAR, DLRL, HYDERABAD, INDIA

Through the earth communication is usually done in the VLF or ELF range. This is because of the increased depth of penetration possible with skin depths of the order of 100 meters. This paper deals with uplink (underground to surface) wireless VLF/ELF communication in coal mines. The main source of noise at the mine surface is due to power line interference at harmonics of the power line frequency. The effectiveness of spread spectrum coding in combating this noise is described here.

The uplink uses PSK at a bit rate of 20 bits/sec with the carrier at 2.5 kHz. Bukofzer and Buettner (URSI meeting, June, 1989, p.187) describe a similar communication link. The addition of spread spectrum coding with maximum length sequences of length $N=2^{n-1}$ with n ranging from 3 to 7 is considered here. Typically power line interference is an order of magnitude greater than the signal strength and several orders of magnitude greater than the atmospheric noise. Our analysis also considers the presence of Gaussian atmospheric noise as given by CCIR 322 in addition to the power line interference.

The probability of error was calculated as a function of spread spectrum sequence length N. It dropped from 10^{-1} in the absence of spread spectrum coding to 10^{-5} for N=31 at ITA=375 amp-m^2. (ITA refers to the product of transmitter loop current, the number of turns, and the loop area). Further increase in N provided only a marginal improvement. For N=31, the bandwidth required approaches that of the system and further increases in N may be infeasible anyway. At N=15, the effective noise due to power line interference dropped below the atmospheric noise, again indicating that the optimum sequence length is between 15 and 31.

The calculations were done using different bit rates, ITA values, mine depths, etc. When the bit rate was reduced to 12 from 20, the error probability reduced from 10^{-3} to 10^{-5} for ITA=125 and N=31. For ITA=125 and a bit rate of 20 bits/sec, the optimum sequence length N was closer to 63 than 31.

THE ANALYSIS OF DOWNCONVERTER DESENSITIZATION IN THE PRESENCE OF NOISY LOCAL OSCILLATOR AND AN UNMATCHED ANTENNA

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Abstract:

The paper considers the noise products generated at the mixer's I.F. port by the Local Oscillator's Far From the Carier A.M Noise and Phase Noise. A method to calculate the Noise Figure of an integrated front-end, configured with a mixer as the input element, is suggested.

When a portion of the noisy L.O signal leaks through the R.F. port of the mixer, and than reflected from the antenna back into the R.F. port, baseband noise will appear at the I.F. port, causing desensitization. This baseband noise is significant when the total delay for that path is in the same order of magnitude as $1/BW_{I.F.}$ (where $BW_{I.F.}$ is the ultimate I.F. bandwidth).

An original, accurate, low cost measurement set-up, is suggested. This set-up enables the simulation of any practically matched antenna, when measuring the mixer's convertion loss and noise figure, and to perform A.M and Phase Noise measurements on the Local Oscillator driving the mixer. Distinguishing between A.M and Phase noise is based on D.C. measurements at the I.F port. The accuracy obtained is good, since the leaky signal received is synchronic with the L.O., from which it was derived. Thus no synthesiser is required for that measurement.

Measurement results of a typical mixer and it's L.O. A.M. and Phase Noises are presented in table 1. As seen from that table, for a 2:1 VSWR antenna (simulated), at 10 MHz both types of noise contributed significantly to the output noise, while causing up to 15 dB desensitization due to Phase Noise, andup to 5 dB desensitization due to A.M. Noise. At 1GHz both noises were insignificant.

Table 1: Measurement results.

	f I.F.	10MHz		100MHz		1GHz	
	Γ_a	-25dB	-10dB	-25dB	-10dB	-25dB	-10dB
MIXER $K_{\ell,r}$=20dB	C.L.ϕ	7.9dB	8.5dB	7.8dB	7.8dB	6.3dB	6.6dB
	C.L.a	7.9dB	8.0dB	7.8dB	7.9dB	6.3dB	6.6dB
	N.F.ϕ	10.5dB	23.2dB	8.5dB	11.3dB	6.2dB	6.6dB
	N.F.a	10.5dB	13.6dB	8.5dB	8.7dB	6.3dB	6.6dB
L.O.,D.L.= +15dBm	n_ϕ	------	129dBc/Hz	-----	141dBc/Hz	--------	--------
	n_a	------	139dBc/Hz	--------	----------	--------	--------

ESTIMATION OF POLARIZATION CHARACTERISTICS IN THE PRESENCE OF NOISE

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Three different methods for Estimation of Polarization Characteristics are described and compared. These methods are (1) an Eigenvector Method (2) a Direct Method and (3) an Adaptive Nulling Method.

Two different characterizations of the Polarization are used. The first involves Ellipticity and Tilt Angle; the second involves Relative Magnitudes and Relative Phases of two orthogonal electric field components. Each characterization breaks down for either circular or linear Polarization. For instance, Tilt Angle is not defined for circular Polarization. The combined representation covers the complete range of Polarization.

A simulation has been carried out to determine errors in each of the quantities Ellipticity, Tilt Angle, Relative Magnitude, Relative Phase as a function of those four variables and of single-to-noise ratio. The results show that all three methods are effective. Methods (1) and (2) yield identical results. For small signal-to-noise ratios, methods (1) and (2) are more accurate than (3). For large signal-to-noise ratios, the three methods merge. The methods are rapid and accurate.

A KNOWLEDGE-BASED APPROACH TO MULTISENSOR AND FULL POLARIMETRIC TARGET IDENTIFICATION

J. Richard Huynen
P.Q. Research

In this paper we review some approaches towards target identification (TI), which uses the full polarimetric target return, and which could include other multisensor data input. General target identification is a task which still awaits a theory. Most of what is called TI at present ultimately depends on a human observer to recognize and identify the targets at hand from scenery. There is an appalling lack of awareness of significance between data obtained on one hand and reality of targets conceived, on the other. That these two are not synonymous is clear, if we look at the same targets under different circumstances, different environments, different aspect angles with different sensors, etc. There is a "constant" somewhere hidden within the barrage of data we obtain, and which should tell us that there is a target (detection) and secondly, that it is a specific physical object, we are trying to identify.

There is simply lacking at present a general theory of target ID, which identifies physical targets without human perceptive intervention. The approach presented here is an application of a general theory of target identification which the author developed [1] and which now has been completed. The novel part consists of an algorithmic justification for the author's polarimetric target decomposition theorem which can be extended to multisensor target data inputs.

The algorithmic process is written as

$$Q^2 |p_A\rangle = |q_A\rangle$$

where Q^2 stands for the extended target coherency matrix, $|p_A\rangle$ is the algorithm to be employed, and $|q_A\rangle$ is the average single target which is extracted from the target database. Hence the process:

$$Q^2 \rightarrow |q_A \times q_A|$$

is that of selection of a single object from the target input data.

The general approach for multisensor input can already be found in [2]. This procedure clearly singles out a single preferred object in contrast to an eigenvalue decomposition where a choice among the possible eigen-targets still must be made.

References

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2. Huynen, J.R., "Towards a Theory of Perception for Radar Targets" in *Inverse Methods in Electromagnetic Imaging*, W.-M. Boerner, Ed., pp. 797-822, D. Reidel Publishing Co., Dordrecht, The Netherlands, 1985.

THE CONCEPT OF THE POLARIMETRIC MATCHED SIGNAL AND IMAGE FILTERS: APPLICATION TO RADAR TARGET VERSUS CLUTTER OPTIMAL DISCRIMINATION

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In radar polarimetry it is the objective to enhance useful target signatures and at the same time reduce the undesired background clutter in high resolution radar imaging. With the recent advances in POLarimetric Synthetic Aperture Radar (POL-SAR) systems design, it is now possible to obtain complete coherent scattering matrix [S] information on a pixel-by-pixel basis for POL-SAR recordings simultaneously at three separate bands (JPL/DC8:P/C/X). Provided such complete POL-SAR four complex channel data sets are available, it is possible to accomplish useful target versus undesirable clutter separation and discrimination by applying the PMIF method. In PMIF the individual pixel matrices are optimized using the three stage procedure and statistical histograming. It is then shown how optimal target versus clutter discrimination and image contrast enhancement is achieved provided the average characteristic target polarization states differ sufficiently from those of the averaged clutter polarization states. The PMIF method is demonstrated using recent JPL/DC8-P/C/X-band POL-SAR data sets of the San Francisco Bay area.

POLARIZATION VECTOR TOMOGRAPHIC IMAGING: ANALYSIS OF THE POLARIZATION CORRECTION TERM

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The depolarization effects in vector diffraction tomography are investigated, which result mainly from the terms $(\nabla\varepsilon)/\varepsilon$ and $(\nabla\sigma)/\sigma$ in the wave equation. Because these terms are hitherto not being considered in the Born and/or Rytov approximations, a simplified model is introduced. For the inverse problem of image formation, oblique incidence on a lossless dielectric circular cylindrical scatterer is considered for the case of plane wave interaction at microwave frequencies. Because the radiation wavelength is comparable to the size of the object inhomogeneities, in diffraction tomography, we must consider the wave nature of the scattering problem and solve the inverse problem correspondingly. By considering the problem in its wave nature, we can account for such phenomena as reflection, refraction and depolarization, all of which occur in diffraction tomography, where here major emphasis was placed to determine the effect of depolarization using the Born approximation. The results of this first order polarization correction study show that depolarization effects should not be neglected in the formulation of microwave (vector) diffraction tomography and that more extensive studies are required in order to make vector diffraction tomography work in practice.

OPTIMAL POLARISATION PROCESSING OF PASSIVE MICROWAVE RADIATION

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Moscow Civil Engineering Institute

Generally, the signals of microwave radiation itself are random processes, that's why processing such signals must be carried out within the framework of the filtration theory. Considering the signals of radiothermal radiation objects in the form of Markovian random processes makes it possible to design the optimal receivers of such signals on the basis of the methods of the Markovian theory of nonlinear filtration synthesis. It is supposed that receiving mutually orthogonal polarized components which are transformed into signals with random phases and amplitudes in the receiving channel is carried out. The synthesis of optimum in terms of the criteria of the parameters rootmean-square errors minimum signals receiver with the use of a priori stochastic differential equations for the description of dynamic amplitudes and phases of the signals orthogonal components has been accomplished. The Relay model is used as the model for signals amplitudes changes. The equal distribution is taken for the phases changes. As a result the receiver structure will contain two processing channels each of which contains the AGC and PLL systems. The numerical analysis of root-mean square errors of amplitudes and phases selection is fulfilled. The synthesis of optimal receiver of thermal radiation signal is done in the same way if we use the direct brightness temperature. The model of changing brightness temperature in the form of the Gaussean model. As a result we get a two channel receiver with tracking targets the performance of which is determined by the performance of low-pass special filters. As before the estimations of root-mean-square errors in brightness temperature filtration have been obtained. As the structure data were synthesized within the framework of minimum mean-square error criterium optimization, brightness temperatures estimations obtained provide maximum accuracy of their selection. It should be pointed out that this approach is rather limited due to the fact that the Gaussean approximation aposteriory probability density of the parameter being determined is assumed. Although this situation is widely used in pratice of radiometry the above condition is not observed in some cases. As additional investigations show that the use of non-Gaussean approximation doesn't result in changing a receiver structure but affects the type and characteristics of the structure filter.

PROSPERTIES OF SCATTERING MATRIX STATISTICS

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URSS, Moscow

Moscow Civil Engeneering Aviation Institute

For the class fluctuating obkects the law of changing multi-size density of probability distribution for scattering matrix complex elements are considered. Its invariance to the polarization basis remplacement is shown. Similar results have been obtained for correlation and covariance matrices. Transformations of mean values and dispersions of scattering matrix elements are considered separately, invariance of these elements dispersions sums are proved, their extreme values are calculated. This makes it possible to obtain determining nonequalities for dispersion values. The concept of Graves generalized matrix is introduced and its transformations are found. It is shown that the elements of correlation matrix are not independent and there exist corresponding limitations for them. The results of scattering matrix elements statistic simulation based on random timely changing proper values and coordinates of the proper basis on Poincare's sphere for this matrix are given. It gave the opportunity to simulate distribution laws for real and imaginary elements of the scattering matrix, their modules and arguments, anositropy extent, complete coss-section, generalized phase, matrix determinant. The results obtained made it possible to determine digital characteristics of these random values (the mean value, dispersion, excess, etc) and to calculate correlation moments and functions. We could show in the simulation process that distribution laws obtained differ greatly from the universal laws obtained by classic ways of simulation but they are in conformity with experimental results. The extent of probability distribution density for anisotropy extent, modules and phases of scattering matrix elements are calculated within the framework of object presentation as a system of independent reflectors. Systematizing the obtained on the basis of Pearson's distributions and checking their correspondance to probability densities widely used are carried out. The results obtained are compared to the experimental data which makes it possible to speak of rather stable laws for a wide class of objects. This, in its turn, opens some possibilities for creating polarization adaptive systems which can be used in future for interference reflections suppression.

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(cont.)

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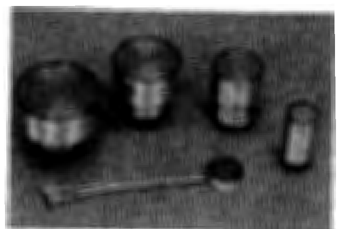

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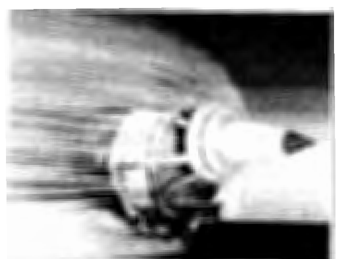

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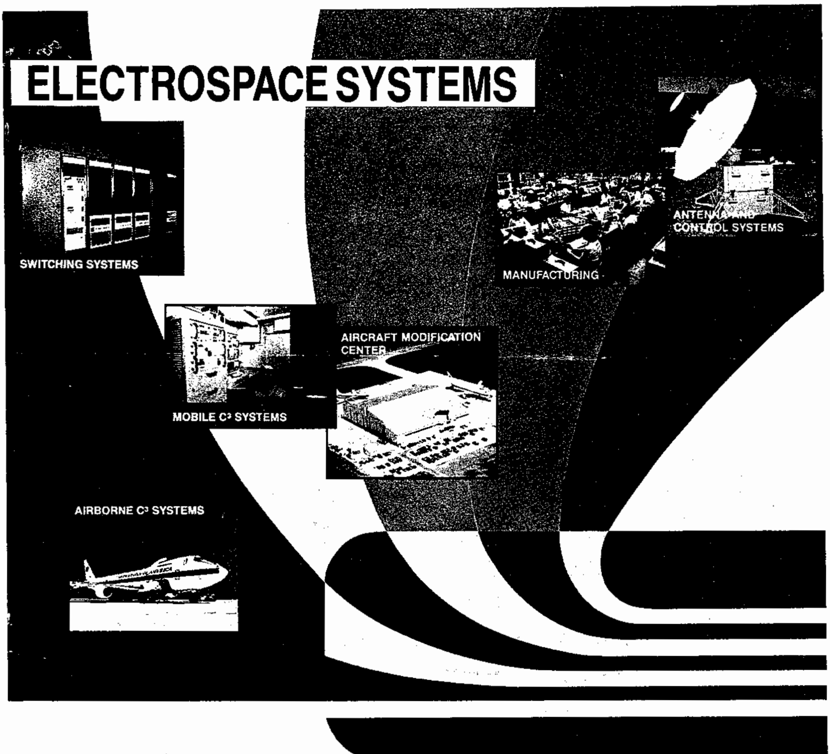
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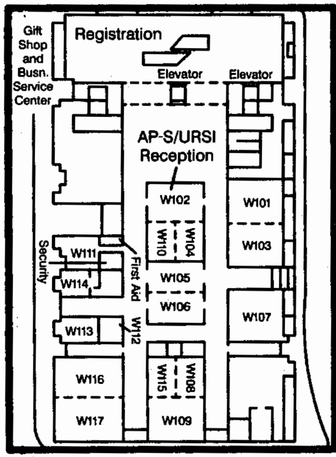

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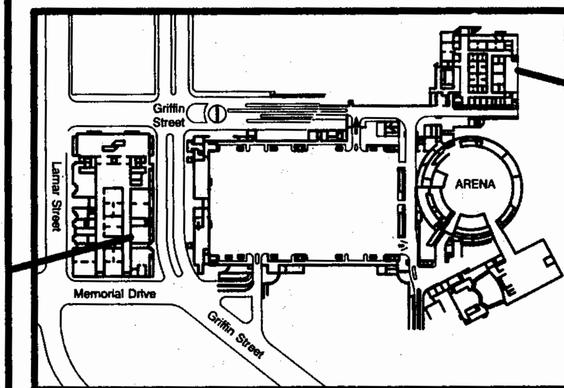

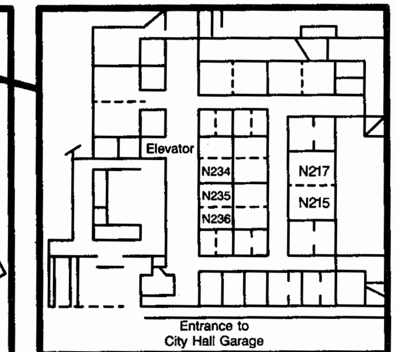

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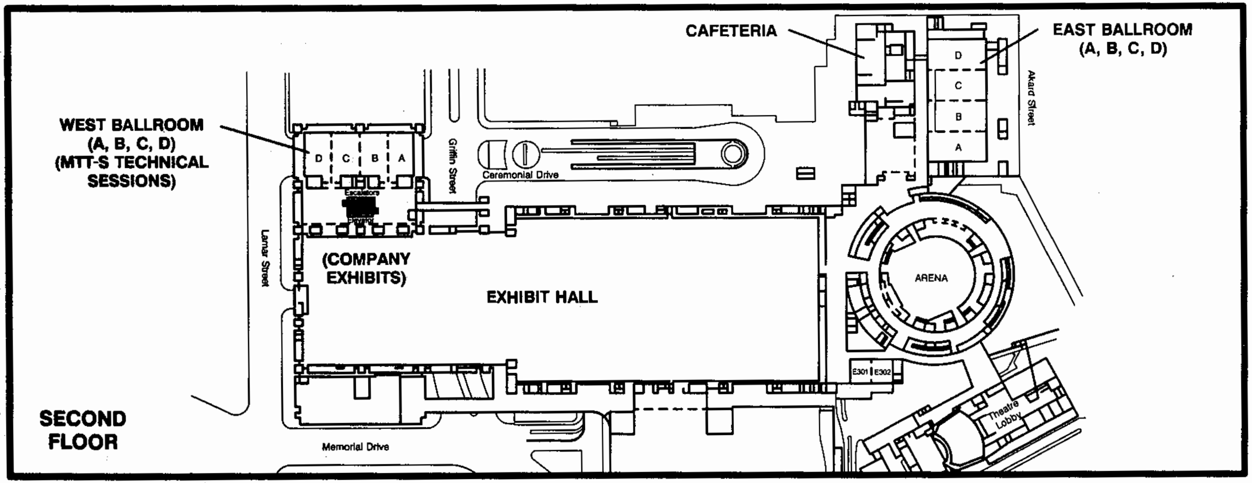

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Radio Science Meeting
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The 1991 North American Radio Science Meeting, sponsored by the U.S. and Canadian National Committees for U.R.S.I. and the International Symposium sponsored by the I.E.E.E. Antennas and Propagation Society (AP-S), will be held jointly in the Social Sciences building at the University of Western Ontario, London, Ontario, Canada from June 24 to 28, 1991. The technical sessions for both will be coordinated to provide a comprehensive and well-balanced program. All Commissions of U.R.S.I will be included and a USNC/CNC/URSI sponsored Student Prize Paper Competition will conducted. Workshops and Special Courses will be offered by AP-S.

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***** AFTERNOON SESSIONS ***** 1:15PM - 5:00PM *****				
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