W. A. Davis

1988 URSI
RADIO SCIENCE MEETING
International Union Of Radio Science

PROGRAM AND ABSTRACTS

U.R.S.I.

June 6-10, 1988

Syracuse University Inn and Conference Center
at
Syracuse University
Syracuse, New York 13221

NATIONAL ACADEMIES OF SCIENCE AND ENGINEERING
NATIONAL RESEARCH COUNCIL
OF THE
UNITED STATES

1988
RADIO SCIENCE MEETING

PROGRAM AND ABSTRACTS

SPONSORED BY

THE UNITED STATES NATIONAL COMMITTEE FOR URSI

SYRACUSE UNIVERSITY

SYRACUSE, NY

JUNE 6-10, 1988

IEEE Antennas and Propagation Society
International Symposium
and
URSI Radio Science Meeting
Syracuse, New York
June 6-10, 1988

Welcome to Syracuse University

On behalf of the Steering Committee, I extend a warm welcome. This joint conference will be held on the campus of Syracuse University, Syracuse, New York, at the Sheraton University Inn and Conference Center. Syracuse University is a private coeducational institution with an enrollment of about 16,000 and with strong programs in electrical and computer engineering, geography, political science, computer science, physics, and public administration. It is located on a hill about a mile from downtown Syracuse. The City of Syracuse is located on the eastern edge of the Finger Lakes Region in Central New York. The Syracuse area was settled shortly after the Revolutionary War. Its history includes the Iroquois Confederacy, the early French explorers, and the Erie Canal which ran through the center of town at one time.

In 1988, we celebrate the centennial of Heinrich Hertz's basic antenna experiments, which we regard as the key experimental verification of Maxwell's equations. Our Hertz Exhibit describes those basic experiments. Take the time to visit this unique exhibit in the Goldstein Auditorium of the Schine Student Center.

Please note the outstanding talks and slide shows on Monday and Tuesday night on the History of Onondaga Lake and Benjamin Franklin, respectively.

1988 marks the third year of our industrial exhibits. These are located in the Goldstein Auditorium at the North End of the Schine Student Center. Coffee and refreshments will be available, as usual.

Social events are planned for every evening, Sunday through Wednesday. There is a reception Sunday night at the Sheraton. On Monday there is an hors d'oeuvres dinner and reception at the Everson Museum. A New England style clambake will be held Tuesday night at Drumlins Country Club nearby. Finally, the Annual Awards Banquet will be held on Wednesday at the Hotel Syracuse.

The technical sessions of the symposium will be completed on Thursday. Friday will be devoted to short courses and workshops. Subjects covered this year include Moment Methods Applied to Transmission through Apertures, Persuasive Presentations, Time Domain Electromagnetics Measurements, MM Wave Propagation through the Atmosphere, Differential Equation Based Finite Methods, and Microwave Imaging. This is a unique opportunity to acquire state-of-the-art knowledge at a very minimal cost.

For those who have the time and opportunity, there are many interesting places nearby to visit: Niagara Falls, Thousand Islands, the Adirondacks, the Finger Lakes, Cooperstown, Watkins Glen, and Cornell University. Visit the hospitality suite (Room 316, Sheraton) for information on these trips.

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David A. Hill	Edip Niver	Richard Ziolkowski

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Monday AM

URSI-B Session 1

TRANSIENTS: PULSES AND POLES

Chairmen: D. L. Moffatt, Ohio State University; B. Audone, Aeritalia

Room: Sheraton Amphitheater *Time*: 8:25-12:00

GENERATING ELECTROMAGNETIC DIRECTED ENERGY PULSE TRAINS*

Dr. Richard W. Ziolkowski
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and
Prof. Ioannis M. Besieris and Mr. Amr Shaarawi
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Exact electromagnetic directed energy pulse train (EDEPT) solutions of the scalar wave and Maxwell's equations are described in this paper. These EDEPT 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. [Ziolkowski, URSI General Assembly, Tel Aviv, Israel, 1987] These EDEPT solutions have also been reproduced with a novel representation involving a decomposition of the wave equation into forward and backward propagating plane wave solutions. [Besieris, J. N. Brittingham Honor Session, URSI Symposium, Blacksburg, 1987]. Pulses with these very desirable characteristics have a number of potential applications in the areas of directed energy weapons, secure communications, and remote sensing.

The physical realizability of the EDEPT solutions can be simulated by launching them from a finite planar array of point sources with the causal, time-retarded Green's function. The driving functions for the array elements are determined by the exact solutions. It will be shown that these EDEPT solutions can be generated by a finite, planar array of sources. A number of issues connected with the general stability of these MPS pulses when they are launched from a finite array have also been considered. Spatially windowing the aperture distribution; i.e., introducing an additional aperture taper, actually helps the pulse reconstruction. It decreases the number of array elements required, but at a cost of slightly larger array sizes; and removes much of the late time noise present in the array-generated signals when undersized arrays are considered. Numerical simulations have also shown that the basic characteristics of the MPS pulse are maintained even if Gaussian noise is added randomly to the array's driving functions.

Because the MPS pulse naturally occupies a volume of space, it is believed that a planar array may be a very inefficient source and that a nonplanar array/source may be better suited to launch this pulse. One potential candidate under consideration is an open, finite circular waveguide. Results from our reconstruction analysis for this potential EDEPT source will also be presented.

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* This work was performed in part by the Lawrence Livermore National Laboratory under the auspices of the U. S. Department of Energy under contract W-7405-ENG-48. This work was sponsored in part by the Strategic Defense Initiative Organization, Office of Innovative Science and Technology, under management by Harry Diamond Laboratories.

INSTABILITIES IN TIME-MARCHING METHODS FOR SCATTERING - CAUSE AND CURE.

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Transient scattering problems in electromagnetics are often formulated as an integral equation over some suitable domain D, usually the boundary or interior of the scattering obstacle, in such a manner that the solution at a time t is expressible in terms of a solution at earlier times $t' < t$.

Discretizing in time and space allows one to obtain the solution at the k^{th} time step $t = k\Delta t$ in terms of the solution at earlier time steps $(k-1)\Delta t$, $(k-2)\Delta t, \ldots$. The occurrence of exponentially growing oscillations is a commonly encountered instability in the usual implementation of this time-marching method. The cause of this instability can be traced to the existence of interior resonances of the scatterer at which the corresponding frequency domain integral equation fails to have a unique solution. It is shown that the instability is an artefact of the numerical method, and can be eliminated in a very simple way by an averaging process. The necessary modifications to any existing computer programs are trivial and increase computational cost only by about 10%.

OPTIMAL T-PULSE FOR EXCITING SINGLE MODE OF A RADAR TARGET (SUMMARY)

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Scattered electromagnetic field of a radar target can be modeled by a linear combination of (damped) sinusoidal functions. The frequency of each sinusoidal function can be used as a signature of that target because of its aspect invariance property. Single mode (frequency) field is easier to process and analyze than multiple-modes field. Therefore, it is desired that one may excite single mode of a target by a signal which must be time limited for practical use. We shall present an optimal T-pulse method for exciting single mode. The T-pulse that we use is time limited (also variable) and has maximal (optimal) energy around a preselected frequency. In principle, the T-pulse can be applied to any highly resonant target. If the preselected frequency is away from any resonant frequencies of the target, the scattered field is virtually zero or very weak. But if the preselected frequency is very close to (or in the band of) a resonant frequency, the resonant frequency will be dominant in the scattered field from which the resonant frequency will be dominant in the scattered field from which the resonant frequency can be accurately estimated. The optimal T-pulse method has been applied to a synthesized thin wire target. A series of interesting plots will illustrate the design procedure of optimal T-pulse and its successfulness in exciting single modes of thin wire target.

NATURAL FREQUENCIES OF A PERFECTLY CONDUCTING CYLINDER WITH INFLECTION POINTS

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Natural frequencies of a two-dimensional perfectly conducting cylinder with inflection points are numerically investigated by the mode-matching method and its extended version [H.Ikuno and K.Yasuura, Radio Sci., 13, 937-946, 1978]. It is noted that the mode-matching method is equivalent to the variational method or the T-matrix method [A.G.Ramm, Scattering by obstacles, Reidel Publ., 370-375, 1986]. For a peanut shaped cylinder and an elliptic cylinder, we have two splitting of the natural frequencies of mirror symmetric objects, away from the degenerate case of circular cylinder. For the peanut shaped cylinder, one of the splitting layers is significantly different from a corresponding sublayer of the elliptic cylinder.

Consider the problem of minimizing the bilinear form

$$\Sigma_{m=1}^{2(2N+1)} |\Sigma_{n=-N}^{N} b_n(N)\phi_n(s_m)|^2 \Delta s_m \qquad (1)$$

on the boundary L of the scatterer under the constraint

$$\Sigma_{n=-N}^{N} |b_n(N)|^2 = 1 \qquad (2)$$

where Δs_m is an approximate line element on L and $\phi_n(s)$ is given by

$$\phi_n(s) = \partial[H_n^{(2)}(k\rho)\exp(jn\theta)]/\partial n \,,\ ds/d\theta=\rho[1+(d\rho/\rho d\theta)^2]^{1/2} \qquad (3)$$

for the H-polarized wave [H.Ikuno and K.Yasuura,1978]. In Eq.(3) $\partial/\partial n$ denotes the outward normal derivative on L and $H_n^{(2)}(k\rho)$ is the Hankel function of the second kind. From (1) under the constraint (2), we have

$$\Sigma_{m=-N}^{N} q_{mn}(k,N)b_n(N) = \lambda_N(k)b_m(N),\ m=0,\pm1,\dots,\pm N \qquad (4)$$

where $\lambda_N(k)$ is an eigenvalue of the matrix $[q_{mn}(k,N)]$, whose elements are defined by

$$q_{mn}(k,N) = \Sigma_{p=1}^{2(2N+1)} \phi_m(s_p)^* \phi_n(s_p)\Delta s_p \qquad (5)$$

where the asterisk denotes the complex conjugate of. This matrix is an entire function of k. Its minimal value $\lambda_N(k,\min)$ is the minimum of the quantity (1) under the constraint (2). Now we consider the points k_{Np}, which are zeros of $\lambda_N(k_{Np},\min)$. From (4) and the nontrivial solution condition, we have

$$\det[q_{mn}(k_{Np},N)] = 0 \ . \qquad (6)$$

The points k_{Np} calculated by Eq.(6) converge to the natural frequencies of the scatterer as N tends to infinity [A.G.Ramm, 1986]. On the numerical algorithm, the convergence property of the solution can be checked by the monotonically decreasing nature of $\lambda_N(k_{Np})$ with respect to the truncation size N. The extended version of the mode-matching method can be used to attain the high convergence rate [H.Ikuno and K.Yasuura, 1978]. Numerical results show that the natural frequencies of the mirror symmetric bodies are simple and each layer splits into two sublayers.

NEW DEVELOPMENTS IN THE STUDY OF RADAR TARGET DISCRIMINATION USING E-PULSES AND SINGLE-MODE EXTRACTION SIGNALS

K.M. Chen*, D.P. Nyquist, E.J. Rothwell, W.M. Sun
P. Ilavarasan and W. Gesang
Department of Electrical Engineering & Systems Science
Michigan State University, East Lansing, MI 48824

In recent years, we have reported research results on a radar target discrimination scheme using E-pulses and single-mode extraction signals. Through theoretical and experimental studies, this scheme has been shown to possess characteristics of aspect independency and noise insensitivity.

Our experimental study has been conducted in a time-domain scattering range constructed on a ground plane. We have now improved this scattering range by increasing the dimensions of the ground plane. Consequently, we are able to increase the sizes of target models because the time-window allowed for the experiment is increased due to the enlargement of the ground plane. The experimental results are improved due to improved S/N ratios of measured radar responses from larger target models.

In addition to this improved ground-plane scattering range, we have also constructed a free-space scattering range for this study. This free-space scattering range consists of a microwave anechoic chamber and a traveling wave antenna system for radiating a Gaussian pulse. The target models are scale models of whole target structures. With these target models, we can illuminate the targets at any aspect angle. New experimental results using this free-space scattering range will be presented.

NATURAL OSCILLATIONS OF AN INFINITELY LONG CYLINDER COATED WITH LOSSY MATERIALS

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The radar cross section of a metallic target can be reduced by coating its surface with a layer of lossy material. When we aim to detect such a target with E-pulse technique, which is based on the natural frequencies of the target, it is necessary to study the effects of lossy coating on the natural frequencies of the target.

We consider an infinitely long conducting cylinder coated with a layer of lossy material and an infinitely long lossy homogeneous cylinder. The natural frequencies and the pole trajectories for these cylinders are studied for a number of dominant resonant modes. It can be shown that the natural frequencies are substantially shifted on the complex plane only when the coating thickness is comparable with the radius of the cylinder. Also when the coating material has a parameter of $\sigma\eta a > 50$ (where σ is the conductivity, η is the wave impedence of free space and a is the radius of the cylinder), it has almost no effect on the natural frequencies of the cylinder.

The Newton algorithm is applied for root searching and Bessel functions are represented by the integral formulas.

ESTIMATION OF THE K-PULSE AND NATURAL RESONANCE FREQUENCIES USING LEGENDRE POLYNOMIAL EXPANSIONS

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and
David L. Moffatt
The Ohio State University ElectroScience Laboratory
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An approach for estimating the K-pulse, which is theoretically an aspect and polarization independent descriptor of a radar target, is proposed. The technique is based on an expansion of the K-pulse waveform in terms of shifted Legendre polynomials and minimization of the combined late-time energy content of the K-pulse response at several combinations of aspect angle and polarization. The dominant complex natural resonance (CNR) frequencies of the target are estimated as zeros of the resultant K-pulse spectrum.

The technique is applicable to any radar target even when the target geometry is quite complicated,since the need for a priori knowledge of CNR frequencies is eliminated. As a result of utilizing a Legendre polynomial expansion in the K-pulse model, the number of variables involved in the optimization procedure is considerably smaller compared to alternative models. Thus, the technique is fast and inexpensive as far as the required computer time is concerned.

In this paper, the results of the technique outlined above are demonstrated for both simple and complicated target geometries.

THE DETERMINATION OF THE REFLECTION COEFFICIENT PROFILE FROM THE K-PULSE AND Γ_L-PULSE WAVEFORMS FOR NON-UNIFORM TRANSMISSION LINES

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Kennaugh et al. (IEEE Trans. AP-S vol. 34, pp. 78-83 1986) stated that the inverse problem of obtaining some parametric information about the non-uniform transmission lines is possible through the available K-pulse and its response waveforms. This presentation will address one aspect of this inverse problem. Using the K-pulse and the returned waveform, the backscattered impulse response of the non-uniform transmission line is obtained via deconvolution. Then the reflection coefficient profile is obtained by keeping track of the multiple reflections due to the non-uniformity in the transmission lines. The non-uniformity is approximated using finite element analysis.

Extraction of the Target Impulse Response and its Application in the Target Discrimination

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Tsinghua University, Beijing, China

Abstrct:

In this paper a transient scattering measurement system including a non-directional transmission-receive antenna, a high speed A/D transform automatic sampling system by the microcomputer controlling and a special soft ware of cancellating various background scattered fields are presented.

In order to observe the contribution of the creeping wave in the impulse response a conducting sphere 66 cm in diameter is used as scattering object. Deconvolution is carried out with real time measured data by the use of conjugate gradient method.

The obtained impulse response of the conducting sphere shows: an impulse appears at the origin, a peak appears at the normalized time $\tau=t/(a/c)=5.45$ which represents the contribution of the creeping wave and there isn't obvious oscillation at earlier time. The presented deconvolution result agrees with the theoretical curve very well, which was obtained by using Fourier Transform method(E.M.Kennaugh Proc. IEEE, 49, 380, 1961).

In order to extracte the complex natural resonances of the scatterer from the extracted impulse response a numerical method has been used.

On basis of the results above mentioned a method for using the complex natural resonances to improve target discriminating technique is suggested.

Monday AM

URSI-B Special Session 4

PDE METHODS

Chairmen: R. Kleinman, University of Delaware; R. Mittra, Univ. of Illinois

Organizers: R. Mittra, D. Wilton

Room: Sheraton Regency C   *Time*: 8:25-12:00

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9:30	**Application Of The Control Region Approximation In Conjunction With Absorbing Boundary Conditions To The Direct Solution Of Electromagnetic Scattering Problems** B. J. McCartin, G. Meltz, United Technologies Research Center; R. Mittra, University of Illinois; L. J. Bahrmasel, United Technologies Research Center	14
9:50	**A Critical Look at Absorbing Boundary Conditions for Partial Differential Equations Arising in Electromagnetic Scattering Problems** R. Mittra, University of Illinois at Urbana-Champaign	15
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11:00	**Progress in FD-TD and OSRC Solution Methods for Electromagnetic Wave Interactions** A. Taflove, G. A. Kriegsmann, Northwestern Univ.; K. R. Umashankar, Univ. of Illinois at Chicago	17
11:20	**Finite Element Modeling of Maxwell's Equations in the Time Domain** R. W. Ziolkowski, N. K. Madsen, Lawrence Livermore National Laboratory	18
11:40	**Discussion**	

SCATTERING VALIDATIONS FOR THE FIELD FEEDBACK FORMULATION

Michael A. Morgan
Electrical and Computer Engineering Department
Naval Postgraduate School, Monterey, CA 93943

Solutions of scattering and radiation problems using partial differential equation based methods require a mechanism for enforcing the far-zone radiation condition. Some schemes that have been employed for this purpose include "infinite elements", the unimoment method, boundary integral equations, the on-surface radiation boundary condition and, the field feedback formulation, (*IEEE Trans. Ant. Propagat., AP-34, Dec. 1986*).

This latter technique, which is denoted as F^3, has three advantages in the time-harmonic case: (1) exactness of mathematics; (2) allowing an independent solution of the boundary value problem involving all material inhomogeneities of the structure, without regard to the incident field or driving excitation; and (3) a system topology which permits a natural iterative solution for the scattered or radiation fields.

The implementation of the F^3 is demonstrated for the case of scattering by inhomogeneous dielectric cylinders. A finite element solution of the interior boundary value problem is used. Special case comparisons are made with eigenmode expansions and alternate finite element solutions, using the unimoment method. Matrix conditioning of the feedback system is addressed from the perspective of internal resonances.

Application of Near-Field Radiation Conditions to the Solution of Electromagnetic Scattering Problems

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The application of so-called near-field radiation conditions provides an approximate boundary condition for truncating solution volumes for finite difference, finite element, and finite integral methods in open region electromagnetics problems. These conditions may be derived by a variety of means, but one promising approach makes use of the theory of pseudo-differential operators. In this approach, the Hemholtz wave operator is asymptotically "factored" into an incoming and an outgoing part. One advantage of the approach is that the sense in which the near-field radiation conditions are only asymptotically correct is clearly revealed. The approach also suggests several possible extensions which may improve the accuracy of the boundary conditions under certain circumstances. The factorization has been obtained for three-dimensional scalar and vector wave equations in a special coordinate system applicable to any smooth surface used to truncate a three-dimensional lattice. Thus the bounding surface need not be spherical, but may be chosen to roughly conform to the shape of the contrast medium. Implementation of the approach in two and three dimensions is summarized.

The "wave equation" representing outgoing waves which is obtained from the factorization provides a relation between normal and tangential derivatives of the field quantities at a surface. When the equation is postulated to apply directly at a conducting surface (the so-called "on-surface radiation condition"), a surface differential equation can be obtained for the surface current induced there. This equation can be solved either numerically or analytically. We have solved a large number of example problems and compared the solutions with either exact solutions or numerical solutions obtained by the method of moments. Some of these results will be presented and discussed.

APPLICATION OF THE CONTROL REGION APPROXIMATION IN CONJUNCTION WITH ABSORBING BOUNDARY CONDITIONS TO THE DIRECT SOLUTION OF ELECTROMAGNETIC SCATTERING PROBLEMS

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L. J. Bahrmasel[+]

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A finite difference frequency domain solution technique, based on a flux-conservative formulation of the discretized generalized wave equation, has been applied to the solution of two-dimensional electromagnetic scattering problems. The scatter is enclosed by a convex outer boundary surface on which the outgoing scattered wave impedance is approximately matched to free space with a higher-order form of the radiation condition. The region contained within the outer boundary contains a set of mesh points suitably selected according to the wavelength and the shape and nature of the scattering target. Each point is enclosed by a convex polygonal control region through which field fluxes are balanced by enforcement of the divergence theorem. This method of solution, known as the control region approximation, is second order accurate and leads to a sparse system of discrete equations which can be efficiently handled.

The placement of the outer boundary and the mesh density determine the accuracy of the solution. Near field plots of the scattered field are presented to illustrate the asymptotic nature of the absorbing outer boundary condition.

A standing wave field in the neighborhood of the outer boundary develops as the artificial boundary is brought closer to the target surface. The relationship between accuracy, location of the outer boundary, and the form of the asymptotic boundary condition is discussed. Possible methods for extending the solution technique to three dimensional problems are presented. Lastly, a hybrid geometric-optics control region finite difference formulation for analyzing scattering from ducts with obstacles is described.

A CRITICAL LOOK AT ABSORBING BOUNDARY CONDITIONS FOR PARTIAL DIFFERENTIAL EQUATIONS ARISING IN ELECTROMAGNETIC SCATTERING PROBLEMS

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Absorbing boundary conditions (ABC's) play the important role of terminating the mesh at an artificial outer boundary in the numerical solution of electromagnetic scattering problems in an open region using the partial differential equation approach. In this paper we take a critical look at these boundary conditions and attempt to answer the following questions that one might raise about them:

a. A number of different ABC's have appeared in the literature. Are some of them better than the others? If so, which ones?

b. Is there a convenient way to extend the scalar boundary condition to the vector case by following a uniform procedure? How?

c. Suppose that we can show $B_n u = O((kb)^{-p})$, where B_n is the nth order absorbing boundary operator applied on the scalar wave function u on an outer boundary located at radius r = b. Does the estimate of error in u, derived by using the above B_n, also equal $O((kb)^{-p})$? If not, can we provide a better estimate?

d. How close can we pull in the outer boundary for the purposes of applying the ABC? Can we impose ABC directly on the surface of the scatterer? If not, why not?

e. If the solutions derived by using the lower order ABC's are not sufficiently accurate, is our best recourse to apply the higher order ABC's to improve the accuracy?

f. Is there an advantage in using the ABC approach over the Unimoment method?

g. Is there a systematic way to deriving the ABC for a waveguide with an arbitrary cross-section?

Where appropriate, representative numerical results will be presented in the paper to substantiate the answers to the questions listed above.

TANGENTIAL VECTOR BASIS FUNCTIONS AND THE TRANSFINITE ELEMENT METHOD

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This paper presents two new procedures for solving the electromagnetic field equations using finite element methods. The first procedure involves the use of a new set of vector basis functions that impose only continuity of the tangential component of the electric or of the magnetic field. These new functions completely eliminate the problem of spurious solutions that appear in solving the vector wave equation with the usual finite element basis functions. The second procedure is called the transfinite element method and extends the domain of application of finite element methods to infinite and singular regions. Examples of electromagnetic wave problems solved by these procedures are presented, along with a description of a computer program that solves both open and closed electromagnetic wave problems on desktop computers.

The fact that the finite element method often produces spurious solutions of the vector wave equation is well documented. In recent years, attention has focused on deriving ways to detect or to eliminate these modes. We show that spurious modes in finite element methods are caused by incorrectly approximating the nullspace of the vector wave equation. The eigenvalue of a nullvector must be zero, but if these nullvectors are incorrectly approximated then the corresponding frequency components are shifted to non-zero values, often to such an extent that worthless solutions are produced. The domain, range, and nullspaces of the vector wave equation must all be approximated in a consistent way to ensure that physically valid results are obtained. We have developed four different ways to do this in both two and three dimensions: In the first method, mixed-order basis functions are defined over rectangular isoparametric elements; in the second, triangular finite element basis functions are defined that interpolate to the field component tangent to the element edges; in the third, C^1 or derivative continuous finite elements are used to generate the approximation functions; and in the fourth method, a special geometric pattern of ordinary finite element basis functions is used that satisfies the appropriate subspace approximation criteria.

The transfinite element method has been applied to potential problems (J. F. Lee, Z.J. Cendes, J. Appl. Phys., 61, 3913-3915, 1987), electromagnetic scattering problems (J.F.Lee, Z.J.Cendes, AP-S Meeting, Blacksburg,VA, 1987), and to microwave problems (J.F.Lee, Z.J.Cendes, IEEE Trans., MTT-35, 1240-1247, 1987). Here we show how this method can be used to obtain the near and far field patterns from antennas and dielectric scatterers.

PROGRESS IN FD-TD AND OSRC SOLUTION METHODS FOR ELECTROMAGNETIC WAVE INTERACTIONS

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The first part of this paper will summarize recent progress made by our research group in finite-difference time-domain (FD-TD) modeling of electromagnetic wave interactions. Topics include: 1. Application to scattering models of 10-wavelength scale three-dimensional structures; 2. Conformal models of impedance-loaded curved targets; 3. Scattering models for two-dimensional homogeneous anisotropic targets, and metal targets having anisotropic coatings; 4. Penetration and coupling models for slots and wires having sub-cell characteristic dimensions; 5. Scattering models for surfaces having rapidly time-varying positions or conductivities; 6. Inverse scattering reconstruction of two-dimensional inhomogeneous dielectric targets; 7. Synthesis of non-physical wave absorbing layers for effective termination of FD-TD space grids; and 8. FD-TD software for the Model CM-2 Connection Machine.

The second part of this paper will summarize our group's recent progress in on-surface radiation condition (OSRC) modeling of electromagnetic wave interactions. Topics include: 1. Application to scattering models of two-dimensional dielectric targets; 2. Application to the scattering of acoustic waves by a reactively loaded sphere; 3. Application to the pulse (transient) scattering of two-dimensional electromagnetic waves; and 4. Application to field penetration into, and scattering from, open waveguides and cavities.

As time permits, the third part of this paper will discuss initial results in full-vector solutions of Maxwell's equations for the nonlinear medium case, obtained using modifications of the basic linear-case FD-TD method. This may be useful for helping to understand certain phenomena in nonlinear optics such as bistability and phase conjugation.

FINITE ELEMENT MODELING OF MAXWELL'S EQUATIONS IN THE TIME DOMAIN*

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We have developed a number of finite element approaches to the numerical solution of the system of partial differential equations that models Maxwell's equations in two- and three- dimensions. In contrast to standard finite difference time domain methods, finite element methods provide the electromagnetic modeler an ability to utilize irregular meshes in describing his/her problem. This geometric flexibility eliminates the need to stair-step curved boundaries. Thus one can achieve similar modeling accuracies with a reduced number of elements in the finite element mesh. The elimination of the stair-stepped approximation is crucial for scattering and aperture coupling problems involving wavelengths smaller than the size of the scattering object.

Approaches based on the conventional finite element methods, a discrete differential form version of Maxwell's equations, a generalization of the finite difference method to arbitrary grids, and several others will be described. The spatial variables are discretized; time is treated as a continuous variable. This reduces Maxwell's equations to a large system of ordinary differential equations that can be integrated forward in time with a number of different techniques. These include explicit methods such as leap-frogging and implicit methods. These finite element approaches have been applied on quadrilateral as well as on triangular meshes. The merits and pitfalls of each of these approaches will be discussed. These will include issues pertaining to the applicability of the different approaches when material interfaces or reentrant metallic corners are present.

An electromagnetic modeler is not concerned only with the efficacy and accuracy of solution algorithms. He/she must also deal with the more practical issues of mesh generation, computer type, algorithm costs, and post-processing of the results. A brief discussion of the methods of mesh generation and post-processing employed with our electromagnetic modeling codes will also be presented. A number of idealized and realistic modeling geometries and the associated numerical results will be presented to illustrate these methods.

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Monday AM

URSI-F Session 5

ROUGH SURFACE SCATTERING

Chairmen: H. R. Raemer, Northeastern University;
M. A. Fiddy, University of Lowell

Room: Sheraton Comstock A *Time*: 8:25-12:00

NUMERICAL MODEL FOR SCATTERING FROM A ROUGH SURFACE.

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There is much interest in the numerical and theoretical modelling of scattering from surfaces. Simple models arise only in the case of small or slowly varying surface height fluctuations. We consider here the latter in the context of obtaining an improved interpretation of ocean SAR images. These images arise from back-scattered fields having non-Gaussian fluctuations and a suprisingly large number of coherent returns given the motion of the surface during the synthesis time of the final collecting aperture.

We have considered the simplest of numerical models based on a variable number of point (and facet) scatterers per ground range resolution cell, the backscatter returns from which are coherently combined into slant range resolution cells. The objective was to determine when this model produced image statistics of the kind observed, in terms of an effective number of scattering centres per resolution cell. A relatively large number of scatterers per resolution cell does not necessarily result in backscattered fields with Gaussian statistics, if the surface roughness, as defined by the Rayleigh roughness parameter ($\Sigma = k\sigma\cos(\phi)$), is not too large (e.g. 6) and the surface height profile is gamma distributed rather than Gaussian distributed. With such a surface and approximately 30 scatterers (or 10λ) per resolution cell, the specific form of the surface height distribution determined the "SAR image" statistics, a gamma distributed height fluctuation leading to a K distributed backscattered field. This remains true even if the number of scatterers is increased by a factor of 10 but Σ is kept fixed (at 6). Gaussian statistics occur if the number of scatterers or Σ increase much beyond this.

We discuss the implications of this numerical model for the interpretation of ocean SAR images.

RESULTS OF STUDIES OF THE DEPENDENCE OF THE MICROWAVE RADAR CROSS SECTION ON SURFACE VARIABLES DURING THE FASINEX EXPERIMENT

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A new measurement program, to develop more precise relationships between the microwave (Ku-band) radar cross section and the ocean surface variables that affect the roughness and reflectivity, is in progress. An extensive data set was obtained during the Frontal Air-Sea Interaction Experiment (FASINEX) during the Winter of 1986 in the Atlantic south of Bermuda. Of interest in this study are the airborne Scatterometer measurements that were coincident with surface wind speed and stress measurements from aircraft and ships, and the directional surface wave spectrum. The airborne radar data set spans several different flights (typically at an altitude of 3000 feet) during which there were a variety of different atmospheric and ocean conditions. The goal of this research is to explain the properties of the Ku-band radar cross section of the ocean (as a function of incidence angle, azimuth angle and wind speed) in terms of the physical forces and variables, such as surface stress and currents, long wave tilting and hydrodynamic modulation of the short Bragg waves. The FASINEX data is the best collection so far because of the detailed supporting information from wave sensors, surface stress, temperature and current sensors in addition to the excellent quality Scatterometer data.

Analysis of this data shows that the radar cross section is more dependent on the surface stress than the wind speed, for both V-pol and H-pol measurements at 50 deg. incidence angle. On several 360 deg. azimuthal scans of the antenna, considerable asymmetry in the radar cross section vs. angle diagram is noticed. This effect seems to be related to the intersecting wave fields at some locations in the experiment region. The interpretation of the Scatterometer data is being coordinated with measurements of the surface wave spectra by the Surface Contour Radar, the RMS surface slope by the ROWS Ku-band radar, and a theoretical model for the surface radar cross section, in the open literature (W.J. Plant, J. Geophys. Res., Sept. 1986, pp. 10,375-10,749)

Measurement and Modeling of the Radar Cross Section of Leaves at 94 GHz

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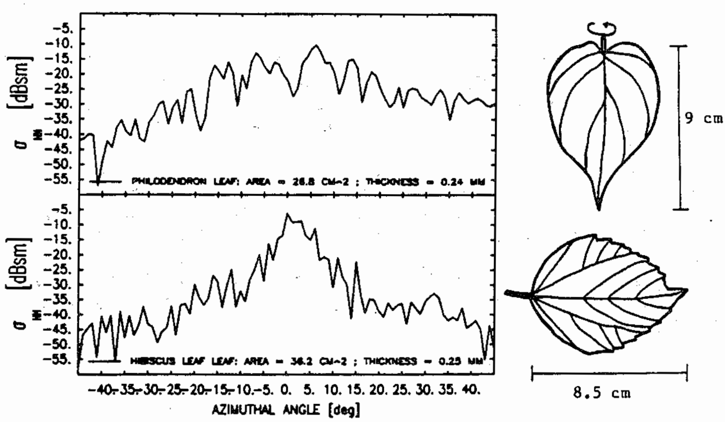
The backscatter from a vegetation canopy at millimeter wavelengths is frequently based on simple models for the individual scatterers. Single leaves are modeled using simple discs or spheroids that do not include surface roughness and other features. However, recent measurements obtained using an HP8510 network analyzer at 94 GHz suggest that the scattering from leaves is more complicated. Although the scattering pattern of smooth, flat leaves exhibiting a strong, narrow main lobe ($\sim 5^\circ$) the scattering patterns of most leaves exhibit a number of peaks over a wide range of incidence angles (20–40°). The fading is believed to be due to constructive and destructive interference from specular reflections from the leaf surface. Measurements of different leaves have been averaged and describe the average radar cross section $\sigma(\theta)$. The fading can be modeled by a Rayleigh distributed random variable ς with a mean $\sigma(\theta)$ and an angular autocorrelation function $R_{\varsigma\varsigma}(\varphi) = \exp(-\alpha \cdot \varphi)$.



STATISTICAL DISTRIBUTION OF THE CLUTTER CROSS SECTIONS OF DECIDUOUS TREES AT LOW GRAZING ANGLES

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We measured the temporal distribution of the clutter cross section of deciduous trees at grazing angles less than 3° and at 3.2 GHz. The clutter cross sections were derived from the measurements made by the S-band wide band mobile radar measurement facility. The temporal scattering cross sections were obtained using a stationary radar illuminating selected clutter patches. The signals reflected from the same clutter patches were received by a mobile receiver located at azimuthal scattering angles corresponding to 180°, 165°, 150° and 135°. The depression angles of the transmitting and receiving antenna were held constant at 3°. The clutter cross sections were measured using instantaneous bandwidths of 200 MHz and 100 MHz. The measured backscatter (180°) cross sections of the deciduous trees were lognormally distributed with a mean of -1.5 dB and a standard deviation of 2.5 dB. No significant variation was observed in the mean or standard deviation for these range resolvable cell sizes. Similar results obtained at other bistatic angles and different polarizations will be described.

Fine Resolution Radar Signature of Sugar Maple, Pin Oak and Pine Trees at C-Band

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ABSTRACT

A very-fine-resolution FM-CW radar scatterometer with a range resolution of 11.5 cm and a footprint 20 cm in diameter at a range of 4.5 m was used to investigate the backscattering and attenuation sources in sugar maple, pin oak and pine trees at incidence angles of 30 and 50 degrees with vertical (VV), horizontal (HH) and cross (HV) polarizations. Constituent defoliation to isolate the primary backscatter sources indicated that at vertical and horizontal polarizations branchlets and stems account for a major portion of the backscatter and attenuation. With cross polarization the backscatter was very sensitive to the linear features of the branches (i.e. petioles, stems, and branchlets) and not the leaves, but at this polarization the leaves accounted for all of the attenuation. For pine trees, needles dominated the backscatter and accounted for most of the attenuation. Cones also showed significant backscattering. At X-band it was found that the leaves usually dominate the backscattering and attenuation in trees, with the exception of the petioles in some cases (R. Zoughi, et. al., Remote Sensing of Environment, vol. 19, no. 3, pp. 269-290, 1986). However, at C-band various constituents of the trees accounted for these two factors. This may be partly due to the fact that at C-band more signal penetration through the branch is possible; thus, more of the constituènts of a tree are exposed to radar signal. It was shown that the moisture content, size and relative orientation of tree constituents affected the backscatter and attenuation properties.

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ENHANCED BACKSCATTER FROM A ONE-DIMENSIONAL ROUGH SURFACE

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and
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There has recently been a great interest in the experimental data reported by Mendez and O'Donnell (Optics Communications, 61, 91-95 (1987)) which shows that when em waves (optical frequencies) are scattered from a very rough surface, there is enhanced return in the antispecular or backscatter direction. As part of a study of the limitations of approximate rough surface scattering models (Papa and Lennon, AGARD Conference Proceedings, Rome, Italy, May 1987) a geometric optics model and a single integral physical optics one (both having small slope restrictions in their derivations) were compared with a general one-dimensional physical optics model for the normalized cross section σ^o. For a Gaussian surface, a six-fold integral expression for σ^o can be reduced analytically to a triple integral (TI) representation, and then, without making any assumptions about high frequency or small surface slopes, the TI can be evaluated numerically using Gauss-Legendre quadrature. In this paper it will be shown that for a range of scattering conditions where the surface slopes are large, the triple integral predicts a significant scattering contribution in the backscatter plane. Neither of the two small slope approximations shows such a large enhancement for those conditions although, for cases where their assumptions are valid, they do show good agreement with the exact representation.

VALIDATED NORMALIZED CROSS SECTION BEHAVIOR FOR A ROUGH SURFACE BISTATIC SCATTERING MODEL

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In a previous paper (Papa, Lennon, Taylor, IEEE Trans. Antennas and Prop, AP-34, 1229-1237, Oct. 1986) the bistatic normalized cross section σ^o for a rough surface physical optics scattering model was reported. Distinct minima are present in the elevation plane scattering patterns and these vary with dielectric constant, polarization and azimuths for that model. In the present study, an analysis is introduced that considers scattering from a surface with two distinct levels of roughness. Two aspects are addressed. First, the validity of the model is established by comparison with experimental measurements. Then a range of results is presented for this more complex surface structure. Experimental data taken at Ohio State University (Cost, "Measurements of the Bistatic Echo Area of Terrain at X-Band, " Thesis, OSU, 1965) are used for the comparisons with the two scales of roughness model for σ^o (including shadowing). Results are shown as plots of σ^o vs. azimuthal scattering angle, ϕ_s. Various polarization cases are considered for selected incident elevation angle, θ_i. The terrain is loam. In general, the agreement between the analysis and the measurements is good and, to the degree of angular frequency at which data was taken, there is evidence supporting the existence of minima in the patterns. The study of the behavior of the two scale σ^o is extensive. Complex variations in σ^o as a function of polarization, frequency and surface conditions (complex dielectric constant) are observed. Both similarities to the single scale results and distinctly different patterns of scattering can be observed depending on the angles under consideration. As was true for the single scale model, the behavior is clearly sensitive to polarization.

ABSTRACT

EFFECTS OF SEA OR GROUND REFLECTION ON HIGH RESOLUTION RADARS AT LOW ALTITUDE

by

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A radar operating at a low altitude over the sea or ground surface (e. g., a ship-borne radar or a radar on a ground-based vehicle) incurs a special multipath problem due to surface or ground reflections. The direct path from transmitter to target-to-receiver is not the only significant path for the signal. Because of the low altitude of the radar, ground- or sea-reflection paths of nearly the same power as the direct path accompany the direct path signal into the receiver. With low time-resolution (or equivalently, small bandwidth) the return is superimposed on the target signal and the signals on different paths cannot be resolved. Thus in most radar applications, this common multipath phenomenon does not affect ranging capability. With very large bandwidth, however, the signals on the different paths are resolved and appear as extraneous target signals with small but resolvable delay differences. The composite returns are not always easily interpretable and may lead to confusion about the true target delay. This efffect begins to be important on shipborne radars with pulses of 10 nanoseconds or shorter or with wideband modulation schemes spreading energy over a band of the order of GHz.

The study reported on in this paper addresses this problem analytically, beginning with a smooth surface model, and extending the model to include both small scale and large scale surface fluctuations. It also includes variations in antenna pattern, transmitted signal modulation, and signal polarization. The original objective was to learn more about the effect of sea scatter on ship-borne radar signal detection and tracking for high resolution radars. The work is also applicable to ground-based or low-altitude airborne radars with very high resolution, although the models require modification to account for differences between characteristics of land and sea surfaces.

Some analytical results are presented for smooth and slightly rough sea surfaces, showing the extraneous peaks and their variation with key system parameters.

SOME PRACTICAL CONSIDERATION IN MODELLING OF GROUND SURFACE SCATTERING FOR COMPUTER SIMULATION PURPOSES

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This paper arises from a research project on a dynamic simulation of returns from natural and man-made terrain features during a radar scenario. The emphasis in this work is on analytically modelling the electromagnetic scattering as accurately as possible within the practical limitations of software technique and availability of pertinent terrain information. The simulation accounts for polarization, Doppler, coherent scattering, multipath and can apply to either monostatic or bistatic radar. Therefore the modelling of the terrain scattering processes must be more accurate than is often the case in radar clutter simulation programs and at the same time computer time must be kept within reasonable bounds.

A key problem arises from the practical requirement to digitize the scattering from a continuous surface. This amounts to a numerical evaluation of a surface integral. At microwave frequencies, the smallest surface patch that can be chosen is many squared wavelengths in area. The phase variations within the patch due to surface height variations are very significant and hence the scattering from the patch is highly sensitive to its dimensions.

As a part of the simulation project, an analytical study is in progress to investigate the scattering from a surface patch of land or water terrain with a view toward optimization of the dimension. We must choose a dimension that will allow the scattering from that patch to be calculated analytically as if it came from a discrete point scatterer at the patch center without a severe sacrifice in accuracy. The reason this is important in the simulation is that a scattering computation may have to be made hundreds or even thousands of times during a scenario. It is necessary to keep the number of surface patches modelled as discrete point scatterers to a minimum in order to avoid an astronomical proliferation of computation time, and hence to choose as large a patch size as is permissible.

Some results are presented showing the variation with patch dimensions of the equivalent scattering cross-section and the polarization matrix for surface patches of typical land and water terrain.

Monday AM

URSI-B Session 6

INVERSE SCATTERING AND TOMOGRAPHY

Chairmen: A. J. Devaney, Northeastern University;
K. J. Langenberg, University of Kassel

Room: Sheraton Comstock B *Time*: 8:25-12:00

8:30	**Multidimensional Electromagnetic Vector Inverse Scattering** K. J. Langenberg, University of Kassel	30
8:50	**Estimation of Object Location in Diffraction Tomography** A. J. Devaney, G. Tsihrintzis, Northeastern University	31
9:10	**Numerical Stability in Diffraction Tomography** N. Soliman, B. D. James, W. Boerner, University of Illinois at Chicago	32
9:30	**A New Reconstruction Techniques for Microwave Diffraction Tomography** H. Chaloupka, M. Schuller, Bergische Universitat Wuppertal	33
9:50	**Identification of Deeply Buried Targets From Backscatter** J. Schneider, I. Peden, University of Washington	34
10:10	**COFFEE BREAK**	
10:40	**On The Bistatic Formulation Of The Physical Optics Inverse Scattering Problem In Radar Polarimetry And Imaging** B. Foo, W. Boerner, University of Illinois at Chicago	35
11:00	**Radar Target Classification From Echo Phase Derivative Measurements:Experimental Evaluation** B. Borden, R. J. Dinger, Naval Weapons Center, China Lake	36
11:20	**The Application of Maximum Entropy Transformations to Inverse Synthetic Aperture Radar Target Imagery** E. K. Walton, Ohio State Univ.	37
11:40	**Optimisation Techniques In The Inversion Of Scattered Field Data** R. J. Wombell, Kings College; C. L. Byrne, M. A. Fiddy, Univ. of Lowell	38

Multidimensional Electromagnetic Vector Inverse Scattering

K.J. Langenberg

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Inverse scattering solutions in two or three spatial dimensions are most often based on either one or all three of the following assumptions

- weak scatterer or physical optics approximation
- far-field approximation
- scalar wave field approximation

At present, only few and highly sophisticated attempts have been made to overcome the first one of these approximations; either the weak scatterer or the physical optics assumption linearizes the inverse scattering problem and, therefore, leads to numerically stable and efficient algorithms. If, additionally, the far-field approximation is valid, the algorithms apply Fourier transform processing only: parameters of the experiment — observation direction and frequency and/or propagation direction of the incident wave — are explicitly related to the target. This procedure can be extended to near-field measurements: the Fourier diffraction slice theorem of diffraction tomography states that the one- or two-dimensional spatial Fourier transform of the data along a straight line or along a planar measurement surface can be mapped into the Fourier space of the target. Exploiting the wave field backpropagation principle of generalized holography, we have been able to derive inverse scattering identities even for nonplanar near-field measurement surfaces, which contain diffraction tomography as a special case. The frequency diversity version of these algorithms can be transformed into the time domain resulting in a diffraction theoretical foundation of the synthetic aperture radar (SAR).

The above unified treatment of multidimensional inverse scattering within the weak scattering or physical optics approximation has been formulated for scalar wave fields. The present paper extends the theoretical evaluation to electromagnetic vector fields introducing polarization diversity. Therefore, inverse scattering identities are presented applying to

- weak scatterer or physical optics approximation
- near-field and/or large scale aperture measurements
- utilization of polarization

ESTIMATION OF OBJECT LOCATION IN DIFFRACTION TOMOGRAPHY

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The problem of estimating the location of a known object from a set of noisy measurements of the wavefields diffracted from the object in a suite of tomographic experiments is addressed using maximum liklihood estimation theory. The problem is formulated in the frequency domain within the context of diffraction tomography where the complex phase of the diffracted wavefield is modeled using the Rytov approximation and the measurements consist of noisy renditions of this complex phase at a single frequency. Within this formulation the estimation problem is shown to be completely analogous to the estimation problem arising in conventional X-ray tomography studied by Rossi and Willsky [*IEEE Trans. Acoustics, Speech, and Signal Processing* **ASSP-32**, p.886 (1984)] and to reduce exactly to this latter problem in the short wavelength limit.

A maximum liklihood estimation procedure is employed to generate an estimate of the center location of penetrable cylindrical objects when the suite of experiments employ incident plane waves whose wavevectors are perpendicular to the axis of the object and the field measurements are performed over straight lines lying outside the object's support volume. Both the "classical" measurement configuration familiar from X-ray medical tomography where the measurement line rotates with the direction of propagation of the probing waves and the fixed measurement configuration where the measurement line remains fixed in space are considered.

The log liklihood function is computed for the case of additive zero mean Gaussian white noise. This function is found to be in the form of the *filtered backpropagation algorithm* of diffraction tomography [A.J. Devaney, *IEEE Trans. Geoscience and Remote Sensing* **GE-22**, p.3 (1984)] where, however, the filter function is no longer the well-known "rho filter" appropriate to least squares reconstruction but is now the projection of the object (centered at the origin) onto the measurement line(s). This result allows the estimation problem to be solved via a tomographic imaging procedure where the noisy data is filtered and backpropagated in a first step and the maximum value of the resulting image is then the maximum liklihood (ML) estimate of the object's location.

The estimation problem treated in the paper is shown to be relevant to a number of practical applications which include estimating the location of tunnels from a limited number of cross-well electromagnetic experiments and the location of tumors in medical ultrasound tomography. A number of computer simulated examples taken from these latter two applications will be presented.

NUMERICAL STABILITY IN DIFFRACTION TOMOGRAPHY

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This research is directed towards improving image resolution of C-band (6 cm wavelength) polarimetric SAR images. Our goal is to improve (by 10x) the typical (100-wavelength) resolution. This increase in resolution may offer better statistical interpretation of rough surface terrain. While there is little diffraction of 6 cm waves from typical terrain structures, the coherent addition of backscattered waves (due to the synthetic aperture) is mathematically equivalent to the problem of first-order diffraction tomography. For this reason, questions similar to those of stability in diffraction tomography may also become important in SAR imaging.

To bypass an excessive formal treatment of stability in inverse scattering, we use Moment Methods to construct the matrix associated with the diffraction problem, and examine its structure with respect to frequency and look-angle diversity. We have observed several interesting properties of this matrix which may yield higher image resolution: it assumes a "diagonal" form when linear flight paths are employed, its "extent" increases as wavelength decreases, and its condition number improves as the number of look-angles are increased.

A new reconstruction techniques for microwave diffraction tomography

by H. Chaloupka and M. Schüller
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In microwave diffraction tomography an unknown permittivity distribution has to be reconstructed from scattered fields measured outside the object and taken at different angles of incidence. To discuss this reconstruction problem the paper is divided into two parts. The first part deals with the partial information about the permittivity distribution available from scattering data for a fixed angle of incidence, whereas the second part is devoted to the problem of combining results gained from different angles of incidence.

As is well-known the polarization current distribution is only partially determined by the observable scattered field. Since the spatial frequency spectrum of the current distribution is determined only at the "Ewald-sphere", not only one but a linear set of different current distributions result. The most difficult problem is to find a proper representation of the set of permittivity distributions being consistent with these current distributions.

In the widely used Born's approximation the problem is simplified by neclecting the effect of the scattered field onto the current distribution leading to a description, where the permittivity distribution is related to the current distribution via a linear operator. Bandlimitation and discretization in the spatial frequency domain allows the permittivity distribution to be represented by a vector (permittivity vector) in a complex finite-dimensional Euclidean space with components given by the sample values of the spatial spectrum. The subset of permittivity vectors corresponding to the scattering data for a fixed angle of incidence are described by an underdetermined linear set of algebraic equations ("hyperplane"). The matrix of these set of equations depends on the measurement configuration but not on the measured data.

In this paper a new method is proposed where in contrast to Born's approximation the effect of the scattered field onto the current distribution is taken into account. Instead of the linear operator in Born's approximation the exact nonlinear operator is used to determine elements of the set of permittivity distributions which corresponds to the set of current distributions. In the discretized model a nonlinear set of algebraic equations for the components of the permittivity vector is obtained. The subset represents a "curved hypersurface" instead of a "hyperplane". If for the sake of computational simplicity the curved hypersurface is approximated by a hyperplane a matrix is obtained which in opposite to the matrix resulting from Born's approximation depends on both the measurement configuration and the scattering data.

In order to find the permittivity distribution both methods require the measurements to be repeated with different angles of incidence. Combining the resulting equations a determined (or overdetermined) system of equations is achieved.

Computer simulations show that the proposed method is superior to methods based on Born's approximation.

IDENTIFICATION OF DEEPLY BURIED TARGETS FROM BACKSCATTER

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Electromagnetic waves in the 30 - 300 MHz. range have been used successfully to probe the earth for subsurface scattering objects such as buried tunnels or cavities. Success has been reported in this wavelength range for both surface and cross-borehole probing. In the latter case, simplifying assumptions are usually made, such as reduction to a two-dimensional problem in which the target lies between the boreholes. Diffraction effects are then found to control the responses that permit the target to be located. This is not the case when the target is positioned to one side of both boreholes, or in the single bore-hole backscatter problem.

This paper examines the use of VHF electromagnetic waves in a single borehole scheme for the detection of scatterers with uniform cross-sections and infinite length. A vertical dipole is the assumed source of illumination, and the host medium is a low-loss dielectric having the measured properties of a particular body of granite of practical interest. The effect of the air-granite interface is assumed negligible. The target cross-section is of the order of the wavelength measured in rock. A frequency domain approach is taken, with conversion to the time domain, typical of single borehole schemes, made by means of a synthetic pulse technique that utilizes the Fast Fourier Transform algorithm. The moment method, wherein the source is approximated as infinite line source, is used to obtain one set of data. The other comes from the T-matrix method, which incorporates an exact formulation of the dipole source and an approximate representation of the target. Although the latter method inherently constrains the scatterer to be finite, the lossy nature of the host medium compensates in the sense that the most significant contribution to the scattered field comes from the target region closest to the transmitting antenna. Further, the incident field diminishes with distance from the source so that only a finite region of the target is visible to contribute to the backscatter. Thus we have one method utilizing an exact representation of the source and an approximation to the target and the other the converse. The two are compared with each other and with the results of measurements made in a laboratory scale model operating at S-band that incorporates lossy ceramic powder, dielectric scattering objects and dipole probes in simulated boreholes. Both time and frequency domain measurements are made with the HP-8510 Network Analyzer and associated instrumentation.

ON THE BISTATIC FORMULATION OF THE PHYSICAL OPTICS INVERSE SCATTERING PROBLEM IN RADAR POLARIMETRY AND IMAGING

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ABSTRACT

An electromagnetic inverse scattering problem for plane wave incidence on a perfectly conducting closed convex scatterer under the physical optics solution is considered for the bistatic case. Using Kennaugh's ramp response formulation, Kennaugh's formula is extended to the bistatic case and the ramp response is applied to radar imaging via the classical Randon problem of reconstruction from cross-sectional areas. Excellent images are reconstructed for the test sphere, using data obtained from the Mie series. To account for the polarization characteristics of vector electromagnetic inverse scattering in both the monostatic and bistatic cases, Bennett's polarization correction to physical optics is applied and extended to obtain an asymtotic relationship between the phase difference of the co-polarized elements of the bistatic scattering matrix and the principal curvature difference at the specular point.

RADAR TARGET CLASSIFICATION FROM ECHO PHASE DERIVATIVE MEASUREMENTS: EXPERIMENTAL EVALUATION

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A new technique has been devised that can use ordinary phase-monopulse tracking data to extract shape information about the target. Measurements of the first three spatial derivatives of the echo phase front are inverted to obtain the moments of the spatial distribution of scatterers. The method requires no detailed *a priori* target knowledge and applies to complex scattering structures with data obtained from very limited (and unknown) aspects. These features make the method a candidate for airborne radar target classification schemes. The theory for this method has been given in *Inverse Problems*, **3**, pp. 623-631 (November 1987).

Until recently, the evaluation of the technique has been based on computer simulated high frequency backscatter data. In this paper, we report on the first experimental results using a 4 element receiving array of open end waveguides operating at 10 GHz. Measurements were taken in an anechoic chamber of scattering from various arrangements of corner reflectors using a stepped frequency radar. The measurements confirmed the ability of the phase front derivative technique to extract the even moments of the spatial distribution of scatterers. The results of measurements with a pulsed radar on a far-field range will also be reported.

THE APPLICATION OF MAXIMUM ENTROPY TRANSFORMATIONS TO INVERSE SYNTHETIC APERTURE RADAR TARGET IMAGERY

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Inverse synthetic aperture radar target imaging typically involves taking the two-dimensional Fourier transform of broad band radar scattering data from a target where the data are measured over a period of time. It is necessary for the target to move in such a way as to impart an effective rate of target rotation about some axis. The resulting image can be considered to be made up of two parts; down-range profiles and cross-range profiles. The resolution of the down-range profiles is constrained by the inverse bandwidth limitation of the Fourier transform, and the resolution of the cross-range profiles is constrained by the inverse time limitation of the Fourier transform. This paper is a discussion of an algorithm to improve the resolution of such profile inversions, often by a factor greater than 20.

The radar scattering from a large class of targets is dominated by a finite set of specular terms. The scattering from each of the specular points as a function of frequency is relatively constant in amplitude and has a linear phase varation, the slope of which is determined by the relative range to the particular specular point. Thus the scattering from each specular point varies sinusoidally with frequency. The total scattering (as a function of frequency) from such a target, therefore, is made up of a finite set of sinusoidal terms. It can be shown that if this condition holds, then the radar scattering from such a target, as a function of frequency or aspect angle, is autoregressive (AR).

There exists a set of algorithms from which the spectrum of an (AR) data set can be determined from a finite number of data points. This paper will discuss the use of the Burg maximum entropy method (MEM) to process ISAR data so as to produce a down-range and cross-range image of a radar target. It will be shown that the resolution of the resulting image is not limited by bandwidth (down-range) or observation time (cross-range), but only by the system signal-to-noise. Examples will be shown where the resolutions obtained were actually more than 20 times better than that obtainable with the use of Fourier techniques.

OPTIMISATION TECHNIQUES IN THE INVERSION OF SCATTERED FIELD DATA

R.J. Wombell[1,2*], C.L. Byrne[2] and M.A. Fiddy[3]
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[2]Mathematics Department, University of Lowell, Lowell, MA 01854,
[3]Department of Electrical Engineering, University of Lowell, Lowell, MA 01854, USA.

A method has been used over the last few years, that inverts limited Fourier data by means of a non-iterative optimisation technique and provides a continuous estimate of a data consistent function in the object domain. This estimate is of minimum norm in a weighted L_2 space, the weighting function being determined from a prior estimate of the object to be recovered. We apply this method to the inversion of limited scattered field data.

Inverse scattering algorithms requiring the optimal inversion of spectral data occur when the first Born or the Rytov approximations are assumed, as in conventional diffraction tomography algorithms. Recently, a new method for inverting scattered field data within the distorted wave Born or Rytov approximations has been developed, and will be described. We have been able to express this inversion procedure also in terms of optimal estimation of the object or scattering function, from limited Fourier data. The distorted wave approximations assume that the scatterer is embedded in a known background, which serves as a prior estimate of the scatterer.

To illustrate the effectiveness of this approach, reconstructions are compared both with and without the use of this optimal estimation procedure, and for the case when the Born and the distorted wave Born approximations are valid. Reconstructions from bistatic microwave scattering experiments will also be presented.

Monday AM

URSI-B Session 8

EM THEORY - MATERIALS

Chairmen: K. Chen, Michigan State University;
I. V. Lindell, Helsinki University of Technology

Room: Schine 304C *Time*: 8:25-12:00

QUASISTATIC FIELDS DUE TO AN ELECTRODE MOUNTED ON A CONDUCTING PAD OF FINITE EXTENT IN A PLANAR STRATIFIED MEDIUM

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In this paper, we analyze the quasi-electrostatic fields generated by an electrode mounted on a perfectly conducting pad of a finite extent in a planar stratified medium. The axis of stratification is perpendicular to the pad. The electrode is maintained at a prescribed potential relative to the pad. This problem serves as a canonical problem which is useful to model some of the antennas employed in geophysical applications. It is more pertinent to tools which are mounted on a pad and operating at low frequencies.

We derive an integral equation in the spectral domain for the normal current distribution on the pad's surface. A method of moments is then applied to solve the integral equation. A proper set of local basis functions is used to represent the unknown normal current distribution on the pad. The basis functions are chosen to satisfy the edge condition as accurately as possible so that the current distribution can be represented by a reasonable number of basis functions. Both the current distribution on the pad's surface and the current flow pattern in the stratified medium are computed.

EXACT IMAGE SOURCES FOR THE DIELECTRIC SLAB GEOMETRY

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Otakaari 5A, Espoo 02150 Finland.

ABSTRACT

Exact image theory, recently introduced for the exact solution of problems involving homogeneous half spaces and microstrip-like geometries, is developed here for the problem of homogeneous slab of isotropic dielectric material in free space.

Expressions for the image sources, replacing the slab and creating the exact reflected or transmitted fields for arbitrary original sources, are given and their numerical evaluation is demonstrated in a form applicable for PC computing. Loss of convergence of the image functions is seen to be due to an expression creating the nonradiating modes guided by the slab. This component is identified and treated separately from the main image expression. The resulting image functions resemble those given earlier for the microstrip geometry [I.V.Lindell et al., JEWA, vol.1, no.2, 95-108] with a little more complication in the expressions. In fact, since the microstrip problem corresponds to an antisymmetric excitation in a slab problem, the microstrip images can be obtained as partial sums of the Bessel function series expansions of the slab image functions.

As possible fields of application, for example, the analysis of finite ground planes in microstrip antenna structures or calculation of coupling from an arbitrary source to the guided waves of a dielectric slab can be suggested. The present image method has also been generalized to media presenting both electric and magnetic polarizabilities.

EDGE EFFECTS ON FIELDS NEAR A STRIP ON A SUBSTRATE

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There is general agreement in the literature that some components of the electromagnetic fields near the edge of an infinite dielectric wedge diverge. This behavior should apply to the region near any sharp edge in a dielectric body.

We have computed the fields scattered from an incident, plane, monochromatic wave by a homogeneous, infinite, dielectric strip of finite cross section on a homogeneous half-space. We have reduced the problem to the solution of a system of integral equations for functions defined on the boundaries between the different media. These unknown surface fields, which also become singular at the edges, are equal to the jumps in the normal derivatives of auxiliary fields that coincide with the physical fields in some of the regions.

In particular, we have computed the energy flux density near the surface of a trapezoidal silver strip on a glass substrate, a configuration that may lend itself to measurement by near-field optical scanning. The dimensions of the cross section of the strip are a fraction of the wavelength of the incident light.

The surface fields are computed only at the centers of segments that cover the cross section of the boundaries, not at the edges themselves. Nevertheless, the computed surface fields become large and oscillate near the edges.

The electromagnetic fields are computed by integration over the boundaries; the integrand is essentially the product of a surface field and the Green function for the two-dimensional Helmholtz equation or its normal derivative. In the region far from the strip the contributions from the surface fields near the edges are unimportant and we can ignore edge effects. On the other hand, the singular behavior of the Green function implies that the fields close to the strip are determined mainly by the values of the surface field on nearby segments. An efficient algorithm requires an interpolation of the surface fields; this procedure does not work well near the edges, where the computed fields also become large and erratic.

If the edges are rounded off, the numerical difficulties diminish. The surface fields become reasonably well behaved at the top of the strip but not at the bottom, where three different media meet. If we are interested only in fields near the top of the strip, we can leave the sharp edges at the bottom. A better solution would be obtained by using in the calculations the behavior of the fields near the edge of the infinite wedge, although this behavior is not known with certainty.

DIFFRACTION BY A RESISTIVE HALF-PLANE IN A DIELECTRIC/FERRITE INTERFACE

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A model for a small step discontinuity in a dielectric half space is that of a resistive half-plane residing on the dielectric/ferrite interface as shown in the figure. Using this model, an E- and H-polarization analysis is presented for the scattered field. The dual integral equation approach or angular spectrum method (P.C. Clemmow, Proc. R. Soc. Lon, 246 A, 1-66, 1953) is employed in this analysis to derive the spectrum of the current on the resistive half-plane. The scattered field is subsequently determined via an asymptotic evaluation of the relevant integral and contingent to a numerical computation of the pertinent Wiener-Hopf split functions. Numerical data will be presented for the scattered field in either region along with a discussion on the branch cut and surface wave contributions.

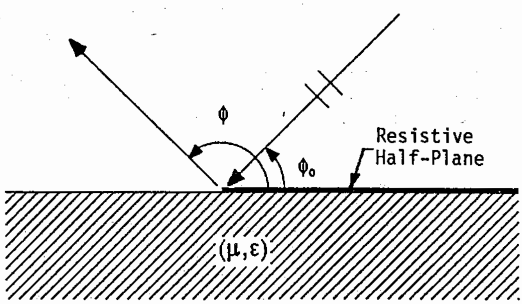

Figure 1. Geometry of the resistive half plane on a dielectric interface.

SHEATH AND PRESHEATH WAVES ON WIRES IN PLASMA.

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A negatively biased wire immersed in a plasma is surrounded by an ion sheath which is known to carry waves called sheath waves (J.J. Marec, G. Mourier, C.R. Aca. Sc. Paris, T. 271, pp 367-70, 10 aout 1970, Serie B).

A new hydrodynamic model of the sheath is presented. It takes into account the inhomogeneity of the sheath and the electron absorption by the wire surface. The sheath is represented by a series of concentric steps of homogeneous plasma. The electron absorption is taken into account by the absorptive boundary condition.

This model was used to study characteristic waves on wires. It predicts the usual sheath wave mode, and a new family of modes. Experiments to test the theory were carried out in a 20-liter plasma chamber.

Compared with the vacuum sheath model, this multi-step model predicts higher attenuation and shorter wavelength for the sheath wave mode. Experimental measurements confirmed these predictions.

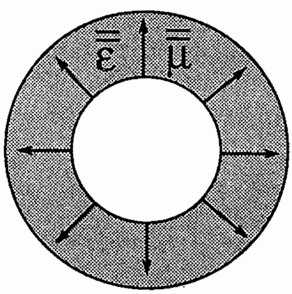
The new family of modes have their energies concentrated in the presheath area. For this reason, they were called "presheath waves". They have shorter wavelengths and stronger attenuations than the sheath wave mode. Moreover, they have low frequency cutoffs and their wavelengths decrease with increased negative bias. Experimentaly, these waves were observed as resonances on monopoles. The measured dispersion and sensitivity to bias confirm the theory.

2-D PLANE WAVE EXPANSION APPLIED TO ROTATIONALLY INVARIANT ANISOTROPIC MEDIA PROBLEMS.

J. Cesar Monzon
Damaskos, Inc. P.O. Box 469, Concordville, PA 19331

Here we study the kind of functions that can be generated by applying variations of the Sommerfeld "wave bundle" integral representation (arising from the problem of diffraction by a half plane) in a polar coordinate transform space. Contours and integrands are selected so that the resulting function becomes a solution of Maxwell's equations in a real space, which is characterized by being rotationally invariant and (homogeneous) anisotropic. The case of period 2π is explicitly treated resulting in an angular series representation for the axial fields valid in an annular region.

Principal axes conformal with cylindrical coordinates.



3-D SURFACE INTEGRAL REPRESENTATION FOR HOMOGENEOUS GENERAL BIISOTROPIC REGIONS

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This paper presents the infinite-medium dyadic Green's function solution to Maxwell's equations in a medium characterized by scalar constitutive relations of the form:

$$\bar{B}=\mu\bar{H}+\beta\bar{E}+\zeta_0\ \nabla\nabla\bullet\bar{H}+\xi_0\nabla\nabla\bullet\bar{E}+\zeta_1\nabla\times\bar{H}+\xi_1\nabla\times\bar{E}$$

$$\bar{D}=\varepsilon\bar{E}+\gamma\bar{H}+\tau_0\ \nabla\nabla\bullet\bar{E}+\sigma_0\nabla\nabla\bullet\bar{H}+\tau_1\nabla\times\bar{E}+\sigma_1\nabla\times\bar{H},$$

where all the coefficients are constants. Such a medium encompasses isotropic, biisotropic and chiral medium as special cases, and we shall refer to it as general biisotropic medium since its analysis resembles that of a biisotropic medium. The aforementioned solution is used to obtain a mathematical statement of Huygen's principle.

Stationary Eigenmodes for two Frequencies in a Medium with Quadratic and Cubic Nonlinearities and Dispersion

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Department of Electrical Engineering
Syracuse University, Syracuse NY 13244

Stationary eigenmodes and their stability during propagation through a quadratically nonlinear dispersive medium, and through a quadratically and cubically nonlinear medium have been investigated earlier (P.P. Banerjee and A. Korpel, J. Acoust. Soc. Amer 70, pp. 157-164, 1981; W. Choe and P.P. Banerjee, "Frequency Approach to Wave Propagation in a Medium with Quadratic and Cubic Nonliearities", submitted to J. Phys. A). While the study of the first was motivated from the knowledge of a balance between nonlinearity and dispersion leading to soliton generation, the study of the second was similarly motivated from a simple physical picture of a quadratic nonlinearity balancing a cubic nonlinearity, and the existence of algebraic solitary waves (P.P. Banerjee and G. Cao, J. Phys. A, to appear, 1988). For a frequency ω_o and its second harmonic $2\omega_o$, it was shown earlier that two stationary eigenmodes, one normal and one parametric, may exist in a quadratically nonlinear, dispersive medium. Stationary eigenmodes in a quadratically and cubically nonlinear medium are, however, purely nonparametric.

In this paper, we develop the spectral evolution equations for the fundamental (ω_o) and the second harmonic ($2\omega_o$) (complex) amplitudes ($\Psi_{1,2}$) for propagation in a medium with quadratic and cubic nonlinearities, and dispersion. Stationary eigenmodes are derived (a) by setting $d\Psi_{\pm1,\pm2}/dx=0$ and (b) by setting $d|\Psi_{\pm1,\pm2}|/dx=0$, where x is the direction of propagation. Our analysis once again verifies the existence of two modes, one normal, and one parametric. The normal mode is characterized by the presence of both the fundamental and the second harmonic, though with a modified phase velocity. The second, or parametric, mode, may, however, contain the case when only the second harmonic exists below a threshold value, while above the threshold, both frequencies coexist. The effective propagation constants, and hence, phase velocities, in this case are also found.

The authors wish to acknowledge the support of the National Science Foundation under Grant Nos. ECS 8603643 and MIP 8657765.

Numerical Experiments with a Double-hump Profile in a Nonlinear Medium

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The propagation of a Gaussian profile through a cubically nonlinear medium shows self-refraction, both in the presence and absence of diffraction (P.P. Banerjee, A.Korpel and K.E.Lonngren, Phys. Fluids 26, 2393, 1983). While, for the right type of nonlinearity, the distance to focus is modified by diffraction, the opposite kind of nonlinearity causes the profile to spread more than in the linear diffraction-limited case. Nonspreading solutions occuring as a balance between nonlinearity and diffraction also exist (S.A.Akhmanov et al, Sov. Phys. JETP 24, 198, 1968; A.Korpel and P.P.Banerjee, Proc. IEEE 72, 1109, 1984).

Numerical experiments based on direct programming of a nonlinear wave equation (H.K.Sim et al, "Simulation of 2-d nonlinear envelope pulse dynamics by a two-step spatio-temporal angular spectrum method", submitted to J. Opt. Soc. Amer.) and experiments done with capillary-gravity waves on water (P.P.Banerjee, A.Korpel and K.E.Lonngren, Phys. Fluids 26, 2393, 1983) have indicated that double-hump profiles, viz., two Gaussians displaced from each other by a certain distance, exhibit features resembling self-attraction and consequent periodic focussing in a cubically nonlinear medium. We verify these effects by starting out from the eikonal equations for wave propagation in a nonlinear medium in the presence of diffraction. The dependence of the distance to focus on the amount of nonlinearity, diffraction and the separation between the two humps are also monitored. A connection is also provided between the two-dimensional behavior of the double-hump profile and the one-dimensional propagation of a double-hump profile in a nonlinear dispersive medium.

The authors wish to acknowledge the support of the National Science Foundation under Grant Nos. ECS 8603643 and MIP 8657765.

Monday AM

URSI-B Session 9

HF SCATTERING FROM PC BODIES

Chairmen: R. G. Kouyoumjian, Ohio State University;
F. Molinet, Mothesim

Room: Newhouse A1 *Time*: 8:25-12:00

UNIFORM GTD SOLUTION ACROSS A CAUSTIC PRODUCED BY A SURFACE INFLECTION POINT

Tom Cwik and Per-Simon Kildal
ELAB
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When using the geometrical theory of diffraction (GTD) and its extensions to calculate fields across transition regions or in focal areas, various special functions are necessary to create uniform representations. These functions produce a smooth continuation of the ray field through the critical areas in a manner which does not greatly detract from the well-known efficiency of the GTD. One such transition function is the incomplete Airy function which is applicable when two reflection points are arbitrarily close to each other and the edge of a scatterer.

A recent application of the incomplete Airy function as a transition function is found in the diffraction analysis of shaped dual-reflector antennas. The shaped subreflector may have a surface inflection point which causes rays that are reflected from near the edge to converge and cross, creating a caustic which is at or near the observation point of GTD calculations. Various other physical systems may be found which similarly create this type of critical region. When a uniform extension of the GTD is used in calculations, the techniques either fail (at the critical point) or will show discrepencies near this point. In this paper an efficient calculation of the incomplete Airy function will be be presented and shown to equal known asymptotic expansions when its argument corresponds to a point away from the caustic. Therefore when calculations are made at or near the caustic the efficient expansion may be applied, while away from the caustic the commonly used uniform versions of the GTD are accurate. Points of crossover between areas where the incomplete Airy function and the uniform GTD become accurate are explicity shown and can be used generally whenever the incomplete Airy function is used as a transition function. The resulting expressions are consistent with the GTD formulation as well as maintaining its computational efficiency.

On A Uniform Asymptotic Solution Valid Across Smooth Caustics of Rays Reflected by Smoothly Indented Boundaries

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It is well known that ray optical solutions fail at and near caustics of ray systems thus requiring one to modify the ray solutions in such regions using uniform asymptotic techniques. A uniform asymptotic solution valid across a smooth caustic of rays reflected by a smoothly indented boundary is presented for both two dimensional(2-D) and three dimensional(3-D) situations. This solution is obtained via a physical optics approximation which is valid because the reflecting surface is assumed here to be fully illuminated by the incident wave. While the subject of caustic field analysis is not new, it appears that other available uniform solutions which recover the geometrical optics field on the lit side of the caustic outside the transition region are generally presented only for the 2-D case; furthermore, they mostly contain parameters that require a detailed knowledge of the caustic geometry and its location, especially for evaluating the field on the dark side of the caustic where real rays cannot exist. As such, they do not provide an explicit prescription for directly calculating the fields within the transition region on the dark side of the caustic where the fields can still be relatively strong, nor within the rest of the dark region. A useful feature of the present solution is that the coefficients and the parameters of the uniform caustic transition functions can be found in a relatively simple fashion. Moreover, it not only uniformly recovers the geometrical optics field described by real rays on the lit side of the caustic outside the transition region, but it also uniformly recovers the proper complex ray field as given recently by Ikuno and Felsen[NATO AGARD-LS-152, June 1987; also paper to appear in IEEE Trans. AP] that exists on the dark side of the caustic outside the caustic transition region. This uniform solution is applied to analyze the fields scattered from smoothly indented cavities containing points of inflection. The accuracy of the numerical results is established by comparison with an independent moment method solution for a special geometry containing an inflection point.

CALCULATIONS OF THE HIGH-FREQUENCY SCATTERED FIELD ON THE AXIS OF A THICK CIRCULAR DISK

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University of Pisa, Italy
R. Tiberio (*), G. Pelosi
Dipartimento di Ingegneria Elettronica,
University of Florence, Italy
R.G. Kouyoumjian
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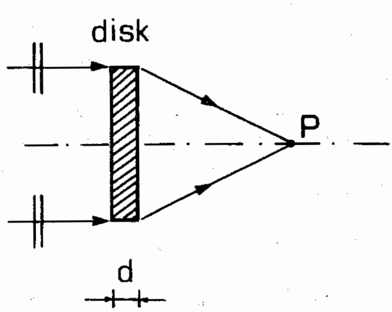
The Ohio State University,
Columbus, Ohio

A high-frequency solution was obtained for the field doubly diffracted by a pair of parallel perfectly conducting wedges illuminated by an arbitrarily polarized plane wave (R. Tiberio et al, AP-S Int. Symp., 1985 and IEEE AP, 1988). Subsequently, the same procedure has been extended to the case of two joined impedance wedges (G. Manara et al, Elect. Letters, 23, 671-672, 1987; M.I. Herman and J.L. Volakis, IEEE AP, 1988).

To demonstrate the applicability of the above mentioned solution to configurations involving curved edges, calculations are presented for the scattered field on the axis of a thick circular disk (Fig. 1). The calculated data are in excellent agreement with those evaluated by a moment method solution.



A Generalized UTD Analysis for the Diffraction by a Wedge with Convex Faces to Include Surface Ray Effects and Grazing Angles of Incidence/Diffraction

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A uniform geometrical theory of diffraction (UTD) analysis for an edge in an otherwise smooth perfectly conducting surface developed previously by Kouyoumjian and Pathak [Proc. IEEE, pp.1448-1461, Nov. 1974] has been applied successfully for solving a large variety of antenna/scattering problems of engineering interest. However, that UTD edge diffraction solution fails for directions of incidence and diffraction which are close to grazing on the curved faces of the wedge; it also does not contain information on the surface rays which are launched on the convex faces of the wedge via edge diffraction.

A generalized UTD(GUTD) solution is obtained here such that it overcomes the above limitations of the previous UTD edge diffraction solution. This GUTD solution can accurately describe both, the rays diffracted by the wedge directly into space, as well as the effects of the surface rays excited/diffracted by the wedge when the illumination is due to a source that can be either on or off the convex faces of the wedge. The present UGTD solution is constructed via an asymptotic matching procedure, and it contains more complicated transition functions than those present in the previous UTD edge diffraction solution. These new transition functions allow for the overlap of two or more asymptotic wave transition regions which are adjacent to the incident, reflected and the various surface shadow boundaries; such an overlap of different transition layers occurs for grazing angles of incidence and/or diffraction. The present UGTD solution recovers, as a special case, the partially generalized UTD edge diffraction solution [Hill and Pathak, 1987 URSI Radio Science Meeting, Virginia, June 15-19] which describes the excitation/diffraction of surface rays as long as one is not close to grazing angles of incidence/diffraction and provided there are no overlapping transition regions. Numerical results will be presented to illustrate the accuracy of this new GUTD solution.

A MODEL FOR THE HIGH-FREQUENCY FOCUSING EFFECT OF STREAMLINED RADOMES

By

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Raytheon Co., MSD
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ABSTRACT

The advent of the combination of solid state sources with MMW guidance systems has resulted in the need for predicting missile radome focusing effects for critical system rf loss budgets. These effects are currently not accounted for in typical missile radome diffraction analysis models oriented toward lower frequencies, where ray shifting is not well defined and furthermore power requirements are less stringent.

In the approach developed, effective aperture areas are formulated with and without the radome. The difference in these areas allows a gain change result which is identified as the ray shifted focusing effect due to the radome geometry. The ray shifting approach of J. H. Richmond has been generalized to an ogival solid wall and weighted for antenna aperture illumination. Further, a ray density function has been applied to each ray bundle traced onto the effective aperture. Tip beam splitting is included appropriately as a decrease in the effective aperture area. Gimballed seeker antenna as well as target ahead conditions are analyzed for a variety of illumination functions. Correlation with measured data is discussed.

DIFFRACTION LOSS IN URBAN MOBILE RADIO PROPAGATION

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and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Diffraction loss is an important factor in the total propagation path loss of an urban mobile radio link. As a mobile receiver moves at a fixed radius from a stationary transmitter, the signal at the receiver will experience rapid fluctuations due to multipath propagation and slow fluctuations due to diffraction and attenuation by buildings and terrain. The net effect of these phenomena is to add additional loss terms to the free space propagation path loss.

The urban propagation environment is modeled as a series of knife-edge obstructions over a conducting ground plane. The distance between receiver and transmitter is assumed to be large compared to the obstacle heights, so that the loss due to a single knife-edge can be computed using Fresnel-Kirchhoff diffraction theory. The effects of the ground plane are calculated using the method of images and included in the diffraction loss estimate. Additional knife-edges are introduced and assumed to be separated by distances which are large compared to their heights. The total diffraction loss is calculated by successive applications of the Fresnel diffraction integral to direct and image ray paths.

A statistical model which characterizes the propagation path profile in terms of number of obstructions, obstruction heights, and separation distances is used to predict path loss in situations with a fixed transmitter and mobile receiver, where the receiver is in motion at a given radius from the transmitter. Diffraction loss predictions are added to the theoretical loss due to multipath and free space propagation to obtain the total predicted path loss. Total theoretical path loss is compared with path loss reported in the land mobile radio literature and with a set of measurements made in Chicago.

A GENERAL PROCEDURE FOR THE EVALUATION OF THE REFLECTED FIELD AT A CAUSTIC REGION WHICH OVERLAPS WITH THE TRANSITION REGION OF A CURVATURE DISCONTINUITY

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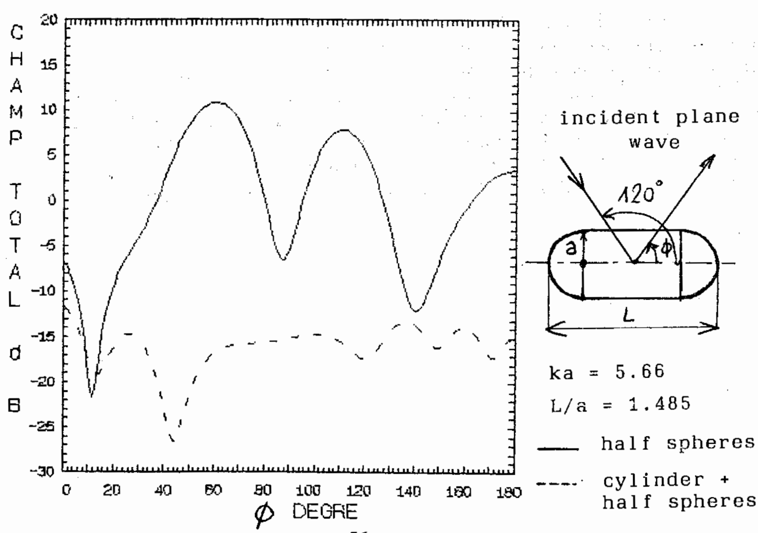
RN 186, 92357 LE PLESSIS-ROBINSON, FRANCE

Starting from the uniform asymptotic (UAT) solution for the diffraction of a plane wave by a line of discontinuity in the curvature, we present a general method for the construction of an integral form of the solution which permits the evaluation of the diffracted field in a caustic region of the GO field. Outside the caustic region, the uniform asymptotic evaluation of this integral is idéntical to the uniform asymptotic solution we started on.

The method is based on a property of the uniform asymptotic expansion of an integral having a saddle point near an end point. It is shown that after the usual transformation mapping the contour of integration on the steepest descend path, the integrant of such an integral verifies a linear first order differential equation, the second member of which is given by the non uniform contribution of the end point. By integrating this differential equation, it is possible to invert the procedure leading to a uniform asymptotic expansion.

As an example, the method is applied to a sphere capped finite cylinder illuminated by a plane wave. Numerical results will be presented. A typical result is illustrated on the figure below.



TRANSFER FUNCTION APPROACH TO ACOUSTO-OPTIC BRAGG DIFFRACTION OF FINITE OPTICAL BEAMS USING FOURIER INTEGRAL

T.-C.Poon, Dept. of EE, Virginia Polytech. Inst. and State University, Blacksburg, Virginia 24061

M.R.Chatterjee, Dept. of EE, SUNY at Binghamton, Binghamton, NY 13901

Most acousto-optic devices currently in use utilize strong interaction effects. Various phenomena occur which cannot be explained by weak interaction theory, such as beam distortion. The strong interaction case of a bounded light beam incident upon a volume grating has been analyzed by various investigators. One approach was to apply a rigorous modal analysis to study Bragg diffraction of Gaussian-profile beams by periodic volume gratings (Chu and Tamir, J.Opt.Soc.Am. 66, pp.220-226, 1976). This led to fairly cumbersome relationships with little physical insight. A coupled wave approach was also used in which analytical expressions were derived for the profiles of the diffracted beams (Moharam, Gaylord, and Magnusson, J.Opt.Soc.Am. 70, pp.300-304, 1980).

A plane wave theory of strong acousto-optic interaction has been developed in which both the light and sound fields are accurately represented by a plane wave decomposition of the fields together with multiple scattering for the interaction (Korpel, J.Opt.Soc.Am. 69, pp. 678-683, 1979; Korpel and Poon, J.Opt.Soc.Am. 70, pp.817-820, 1980). The formalism is applicable not only to hologram type configurations, but also to realistic sound fields subject to diffraction.

In this paper, we analyze the Bragg diffraction of incident light beams of arbitrary profiles by a sharply bounded sound column using the multiple plane wave scattering formalism. Specifically, we apply the formalism to the case of oblique incidence via a Feynman diagram and Laplace tranform approach. The results so obtained are used to define the transfer functions and response functions corresponding to the two diffracted orders. Following this, we then develop a Fourier transform formalism that represents the scattered field amplitudes by means of direct and inverse Fourier integrals. The formalism is applied to the case of an incident light beam with a Gaussian profile, and limiting solutions are obtained for the asymptotic limits of very low and very high soundpressures. These and other results generated from the use of FFTs have agreed reasonably well with those obtained by Moharam et.al. Additional work using the convolution approach is currently under preparation for publication.

Ray Analysis of SEM Resonances of Two Dimensional Finned Cylinders

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Abstract

A ray solution for the SEM resonances of a two dimensional finned cylinder is studied. We demonstrate how the formation of the resonances by multiple ray interactions on the object can be simplified, by considering first the partial resonances obtained by treating the dominant interaction processes in isolation and then, exploring the perturbation caused when these processes are weakly coupled. Some general conclusions are drawn, which enhance the physical interpretation of the resonance mechanism and which can be used to simplify the SEM analysis of a composite object.

Monday AM

URSI-B Session 12

SCATTERING & DIFFRACTION FROM APERTURES & SCREENS

Chairmen: J. Perini, Syracuse University;
D. Hill, Syracuse Research Corp.

Room: Newhouse 262 *Time*: 8:25-12:00

8:30	**Electromagnetic Scattering from and Transmission through Arbitrary Apertures in Conducting Bodies** T. Wang, R. F. Harrington, J. R. Mautz, Syracuse Univ.	60
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9:30	**Reduction of Reflections Using Salisbury Screens** R. Fante, M. T. McCormack, TEXTRON	63
9:50	**Electromagnetic Scattering By A Dielectric Rough Surface in First Order Weiner-Hermite Approximation** C. Eftimiu, McDonnell Douglas Research Laboratories; G. W. Pan, South Dakota State University	64
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10:40	**Second-Order Weiner-Hermite Expansion in the Electromagnetic Scattering by Conducting Surfaces** C. Eftimiu, McDonnell Douglas Research Laboratories	65
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11:20	**Scattering of a Wave at a Periodic Boundary: A Study of the Surface Impedance Boundary Condition** R. A. Depine, V. L. Brudny, University of Buenos Aires	67
11:40	**Radiation from Leaky Waves on Multiple-Layer Dielectric Structures** D. R. Jackson, University of Houston; A. A. Oliner, Polytechnic University; A. Ip, University of Houston	68

ELECTROMAGNETIC SCATTERING FROM AND TRANSMISSION THROUGH ARBITRARY APERTURES IN CONDUCTING BODIES

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The general 3D aperture coupling problem is formulated in terms of an integral equation for the equivalent magnetic current in the aperture, which is numerically solved by the method of moments. The aperture is characterized by two aperture admittance matrices, one for the exterior region and the other for the interior region. These two admittance matrices are determined separately but in a similar manner if the pseudo-image method is used. Numerically workable expressions are developed for the two aperture admittance matrices by decomposing each of them into a half-space admittance matrix and a supplementary admittance matrix. The half-space admittance is relatively easy to compute and has been investigated in the literature. The supplementary admittance matrix is expressed in terms of the generalized impedance matrix of the complete conducting surface (aperture closed). Thus, by combining the existing numerical codes for an arbitrarily shaped scatterer and for an arbitrary aperture in a conducting plane, we obtain a code especially designed for an arbitrary aperture in a conducting surface of arbitrary shape.

The above mentioned general relationship between aperture admittance matrices and generalized impedance matrices is universal (independent of choices of expansion functions and problem geometries). A detailed discussion is given when the complete conducting surface is modeled by planar triangular patches and the electric current expansion functions are chosen as those used by (S. M. Rao, et al., AP–30, 409–418, 1982). In this case, the aperture of arbitrary boundary and the conductor of arbitrary shape are triangulated in such a way that the selection of the magnetic current expansion functions coincides with that of the electric current expansion functions in the aperture region. As a result, the half-space admittance matrices are obtainable by duality from the partitions of the impedance matrices. The supplementary admittance matrices are numerically evaluated easily from the matrix relation in terms of the impedance matrices. The scattering properties and the EM field inside the conducting bodies are also given by matrix formulas. The numerical examples of a rectangular box with a rectangular aperture and a sphere with a circular aperture are discussed.

SCATTERING BY GAPS AND CRACKS

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A matter of increasing concern in radar scattering is the contribution from gaps and cracks where two component structures come together. For the two-dimensional problem of a narrow gap filled with a resistive or impedance material in an otherwise perfectly conducting plane, the integral equations for the currents induced in the gap are approximated under the assumption that $w << \lambda$ where w is the gap width and λ is the wavelength. The resulting equations are analogous to ones occurring in airfoil theory. Exact solutions are derived in special cases and these are used to guide the development of approximate analytical expressions for the diffracted fields which are valid for almost all resistivities of the gap material. By comparison with data obtained from a moment method solution of the problem, it is demonstrated that the results are accurate even for gap widths as large as $\lambda/8$ for H-polarization and $\lambda/4$ for E-polarization, and the application of these formulas to realistic gap geometries is also discussed.

ELECTROMAGNETIC PENETRATION THROUGH NARROW SLOTS IN SCREENS

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Electromagnetic field penetration through a narrow slot in a planar conducting surface is determined in both the frequency and time domains by integral equation methods. Integral equations are derived and solved numerically for the slot electric field, from which the field that penetrates the slotted surface is subsequently determined. Results obtained via the two methods (and the utilization of the FFT) are compared. The validity of both methods is established by demonstrating close correlation between data obtained from computations and those determined from measurements.

The frequency-domain integral equation is solved numerically for the slot electric field, or equivalent magnetic current, by a standard technique utilizing a piecewise linear approximation of the unknown and equation enforcement by pulse testing. The time-domain equation is solved by a scheme incorporating a finite difference approximation for the differential wave operator in the integral equation. This time-domain scheme obviates the need for matrix inversion, thus allowing the solution to be progressively acquired by "marching in time." From knowledge of the equivalent magnetic current, obtained as the solution of the integral equation, the field which penetrates the slot is calculated at various locations for several cases of plane-wave excitation. As a partial check on the accuracy of the solutions, the time-domain slot magnetic current and the resulting field are transformed into the frequency domain via the FFT and are compared to corresponding quantities obtained directly from frequency-domain analysis.

A narrow slot was cut in a large aluminum sheet and an apparatus was fabricated to measure fields. The experimentation was conducted at the Lawrence Livermore National Laboratory on a frequency-domain test range employing a monocone source over a large ground plane. The field was measured at various shadow-side locations for several combinations of excitation and slot length and width. Data were collected for the cases of slots 10 and 15 cm by 1 and 2 mm in the range 0.5 to 10.5 GHz. The agreement of the experimental and theoretical results is excellent.

Reduction of Reflections Using Salisbury Screens

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Design formulae will be presented for the reduction of reflections from planar and curved surfaces using multiple electric and magnetic Salisbury screens. Numerical results will be presented for a number of interesting cases.

ELECTROMAGNETIC SCATTERING BY A DIELECTRIC ROUGH SURFACE IN FIRST ORDER WIENER-HERMITE APPROXIMATION

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We study the scattering of plane electromagnetic waves by a rough surface, $z=\zeta(x,y)$, separating free space from a dielectric (possibly lossy) medium, using Wiener-Hermite expansions to first order for currents and fields. The surface is viewed as a realization of a stochastic process with $<\zeta>=0$.

The Wiener-Hermite functionals $He_n(\zeta)$ possess the improtant property that $<He_m \bullet He_n>=0$ if $m \neq n$, so that they provide orthogonal expansions of currents and fields. As a consequence, even when the expansions are carried out only up to first order, the coherent and incoherent responses contain contributions from all orders of multiple scattering.

The results obtained by this approach are compared to those obtained by other methods.

SECOND-ORDER WIENER-HERMIT EXPANSION IN THE ELECTROMAGNETIC SCATTERING BY CONDUCTING SURFACES

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The surface current induced by a plane electromagnetic wave on a rough conducting surface and the scattered electromagnetic field are sought as expansions up to the second order in Wiener-Hermite functionals of the profile function.

The resulting expressions for the coherent and incoherent cross sections are compared to both the results previously obtained in first order Wiener-Hermite approximation and the results following from other approaches.

SCATTERING FROM NON-UNIFORMLY COATED CONDUCTORS USING AN IMPEDANCE BOUNDARY CONDITION

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An impedance boundary condition imposes proportionality of the tangential components of the total electric and magnetic fields at a surface

$$\hat{n} \times (\vec{E} \times \hat{n}) = C\,\hat{n} \times \vec{H},$$

where C is the proportionality factor and $\hat{n}$ is a unit normal to the surface. This boundary condition is only approximately true and the choice of proportionality factor and the conditions of validity depend on the physical situation being modeled.

For a perfectly conducting object coated with a uniform (i.e., isotropic, homogeneous, and constant thickness) layer of penetrable material, the proportionality factor can be taken to be $C = j\,\eta \tan kt$, where t is the thickness of the layer, k is the wave number in the material, and η is the intrinsic impedance of the material $\eta = \sqrt{\mu/\varepsilon}$. The performance of this approximate boundary condition has been studied in some detail (P. L. Huddleston and D.-S. Wang, URSI Radio Science Meeting, Blacksburg, VA, 1987).

In this paper we generalize this impedance boundary condition to non-uniformly coated conductors. We consider three simple classes of non-uniformities: homogeneous coatings of non-constant thickness, tangentially inhomogeneous layers of constant thickness, and inhomogeneities in the form of multiple layers each of which is uniform. We explore the limits and range of validity of this approximate boundary condition for these classes of problems.

SCATTERING OF A WAVE AT A PERIODIC BOUNDARY: A STUDY OF THE SURFACE IMPEDANCE BOUNDARY CONDITION

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The scattering of a plane wave by a closed surface Σ can be exactly solved by making use of the boundary conditions that state the continuity of the tangential components of the electric and magnetic fields, $E_{//}$ and $H_{//}$. On the other side, if the ratio between those components along the surface (a quantity known in the literature as "surface impedance") is known, the problem can also be solved: the surface impedance (Z) may then be used as a boundary condition that enables us to find the fields outside Σ without solving the wave equation inside the surface Σ. Unfortunately, Z depends not only on the shape and nature of the scatterer but also on the incident field, and so its determination generally involves the whole solution of the problem.

The idea of postulating "a priori" the dependence of Z on the parameters of the problem and using it as a boundary condition to solve the scattering problem has seemed attractive to many authors. Leontovich, for instance, used the approximation $Z=Z_o$=constant to solve the problem of radiopropagation near the earth surface. In the context of the electromagnetic theory of gratings the approximation $Z_o=1/n$ (n being the complex index of refraction of the metal), in conjunction with techniques associated with the perfectly conducting model, was as the basis of a method for calculating grating efficiencies (Depine and Simon, Opt. Acta 30, 313-322, 1983), which provided reliable results for highly conducting metals and surfaces with low local curvature. The validity of the boundary condition, however, remained to be tested, since Z has never been calculated rigorously.

In this work we will present exact calculations of the surface impedance for several gratings. The dependence of Z on the angle of incidence and on the position along the surface will be shown. We will also present the efficiency curves obtained from a method based on the Z_o approximation and compare them to the ones obtained by rigorous methods. Problems that arise as the local curvature is increased and for garzing incidences will be discussed and a possible improvement of the expression will be analyzed.

RADIATION FROM LEAKY WAVES ON MULTIPLE-LAYER DIELECTRIC STRUCTURES

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Previous work has shown that a two-layer substrate-superstrate geometry may yield narrow beamwidths for embedded sources such as microstrip antennas, due to the existence of weakly attenuated leaky waves when the superstrate ϵ_r is large (D. R. Jackson and A. A. Oliner, URSI Abstracts, p. 146, June 1987). Recently this narrow-beam configuration has been extended to multiple-layer dielectric structures, which may produce much narrower beams than those using only two layers (H. Y. Yang and N. G. Alexopoulos, IEEE Trans, vol. AP-35, pp. 860-863, July 1987). This structure consists of a series of layers over a ground plane, with alternating permittivites ϵ_1 and ϵ_2, where $\epsilon_2 > \epsilon_1$. In the present paper a leaky-wave analysis of the multiple-layer structure is given, for an arbitrary number of layers. In particular, two alternative methods are discussed: a resonant cavity model and a power-flow method. Both methods yield the same asymptotic formulas in the high ϵ_r limit, but provide different insights into the physical phenomenon. The formulas predict that the attenuation constant of the leaky waves varies as $\alpha/k_0 \propto (\epsilon_1/\epsilon_2)^N$, with N the total number of layers. Hence very weakly attenuated waves, and therefore very narrow radiated beams, may be produced with only a modest number of layers in this type of structure.

The radiation from cylindrical leaky waves on such structures is then discussed. Using the equivalence principle, radiation formulas for TE_z (H-type) or TM_z (E-type) leaky waves are derived. These results extend to the vector case earlier work by Tamir and Oliner (IEE Proceedings, vol. 110, pp. 325-334, Feb. 1963) for the case of one-dimensional wave propagation, where radiation may be described in terms of a scalar Kirchhoff-Huygens formula. Although applicable to any type of structure capable of supporting a cylindrical leaky wave, these new radiation formulas are applied here to the multiple-layer dielectric structure, in order to show the agreement between the exact patterns and the corresponding leaky-wave patterns of various embedded sources, such as horizontal and vertical electric and magnetic dipoles. The general properties of these new radiation formulas are also discussed.

Monday PM

URSI-B Session 13

TRANSIENTS-PROPAGATION & SCATTERING

Chairmen: D. Kajfez, University of Mississippi;
H. Nakano, Hosei University

Room: Sheraton Amphitheater *Time*: 1:25-5:00

TRANSIENT SCATTERING FROM TWO-DIMENSIONAL CYLINDERS OF ARBITRARY CROSS SECTION

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In a recent paper (Damaskos *et al.* IEEE Trans., AP-33, 21-25, 1985), obtained the TM transient scattering from infinitely long two dimensional conductive/resistive sheets both open and closed. They derived an integral equation for the induced current in time domain by matching the axial incident and scattered E-fields on the boundary of the cylindrical structure. The resultant electric field integral equation is then solved using marching-on-in-time procedure which essentially computes the induced current based on the currents obtained at earlier instants. The obvious disadvantage of this procedure is the accumulation of round-off errors as the solution progresses in time. One simple way of avoiding the error build-up in late time is to develop a procedure which minimizes the round-off error at each time step before proceeding to the next instant.

In this paper, we solve the transient scattering problem of two dimensional cylindrical structures for both TM and TE cases, employing marching-on-in-time method and conjugate gradient method (CG). The CG method is an iterative method which minimizes the round-off error at each time interval before proceeding to the next one. The CG method not only preserves all the properties of the conventional marching-on-in-time procedure but also provides error estimation at each time step. This information may be useful in characterizing the accuracy of the solution obtained. Furthermore in CG method, one can independently choose the time and space sampling intervals, which is not the case for the marching-on-in-time procedure. Numerical procedures highlighting the advantages of CG method along with the results for the case of a strip and cylinder will be presented.

PROBLEMS AND SOLUTIONS ASSOCIATED WITH A WEYL REPRESENTATION FOR TWO-DIMENSIONAL TIME-DOMAIN WAVE FUNCTIONS IN A LAYERED DIELECTRIC MEDIUM

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Two-dimensional time-domain wave functions in a layered, conducting dielectric medium can be expressed in terms of a modified version of Weyl's integral representation [Kuester and Tijhuis, Proc. Nato ARW, Castel Gandolfo, Italy, 1983, 285-292, Martinus Nijhoff (1985)]. The integrand of the Weyl representation is related to the analytic signal in communication theory, and must in general be obtained numerically by solving a one-dimensional time-domain integro-differential equation.

Problems may arise in solving this equation when, in some or all of the layers, the integrand represents an inhomogeneous instead of a homogeneous plane wave. In one part of the spectrum, we have actual non-uniqueness problems corresponding to the occurrence of guided waves. In another part, we have numerical stability problems due to the time-domain formulation employed.

Both types of problems can be circumvented by solving an equivalent frequency-domain integral equation, and by deforming the contour of integration in the Weyl representation. The numerical solution of the integral equation is carried out by a recently developed recurrence scheme [Tijhuis, National Radio Science Meeting, Boulder (1988)]. The evaluation of the integrand for complex values of the time parameter necessitated by the contour deformation is performed with the aid of a chirp Fourier transform [Tseng and Sarkar, IEEE Trans. GE-20, 161 168 (1982)].

*Presently on leave at the University of Colorado at Boulder, with the financial support of the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

A TIME–DOMAIN DIFFERENTIAL SOLVER FOR ELECTROMAGNETIC SCATTERING PROBLEMS

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The objective of this paper is to extend Computational Fluid Dynamics (CFD) based upwind schemes to numerically solve the Maxwell equations to study scattering from objects with layered material mediums. The paper starts with a discussion on the character of the Maxwell equations and shows that they represent a linearly degenerate set of hyperbolic equations. To show the feasibility for applying CFD–based algorithms, first the transverse magnetic (TM) wave form of the Maxwell equations is considered. A finite–volume scheme is developed with appropriate representations for the electric and magnetic fluxes at a cell interface, accounting for variations in material properties in both space and time. This process involves a characteristic subpath integration known as the "Riemann Solver." An explicit Lax–Wendroff upwind scheme which is second–order accurate in both space and time is employed to solve the TM equation. A nonreflecting characteristic based far field condition is applied at the far field allowing the outer boundary of the computational domain to be kept just a few wavelengths from the scattering object. A body–fitted coordinate transformation is introduced to treat arbitrary cross–sectioned bodies with computational grids generated using an elliptic grid solver procedure. For treatment of layered mediums, a multizonal representation is employed satisfying appropriate zonal boundary conditions in terms of flux conservation. The computational solution extending from the object to a far field boundary located a few wavelengths away constitutes the near field solution. A Green's function based on near field–to–far field transformation is employed to obtain the bistatic radar cross section (RCS) information. Results are presented for a number of two–dimensional objects with layered material mediums for both continuous wave (single frequency–time harmonic) and transient (broadband frequency response) cases. The time–domain solver also provides a unique capability for including nonlinear and time–varying effects such as due to a modulated impedance load.

The paper will also provide some extensions of the present work to the transverse electric (TE) wave formulation and the full Maxwell's equations. Coupling of the RCS calculations and the aerodynamic CFD calculations through optimization routines to achieve synergism in the design of aerospace configurations as a future prospect will be the conclusion of the paper.

RESPONSE OF LAYERED MEDIA TO CURRENT SOURCES WITH ARBITRARY TIME BEHAVIOR

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The transient fields of a current source on a layered medium are calculated using the double deformation technique, in which complex integrals are deformed in the transverse wavenumber and frequency planes. Singularities from these complex planes correspond to physical modes of the structure, such as guided and leaky waves, and the relative importance of each to the overall response can be discovered. Unlike the Cagniard-deHoop method, double deformation can be applied to dispersive and dissipative media. Also, the causality of the electromagnetic signal can be shown analytically.

In this paper, a modification to the double deformation technique is presented, which consists of splitting the Fourier transform of the source current into two halves, one for times before the arrival at the observation point, and one after. This greatly increases the range of sources to which the double deformation technique can be applied. Another advantage of the modification, the individual causality and continuity of each mode, will be shown. The relative importance of the different wave modes will be demonstrated, as well as the improvement of this method over more brute-force approaches.

Results will be shown both for line and strip currents on the surface of a coated perfect conductor, for cases where the dielectric coating is both lossless and dissipative. In most cases, only a small number of modes suffices to reproduce the important features of the response, including the arrivals of reflected and lateral rays. The importance of each type of arrival depends on certain features of the time function, especially the initial slope. The response due to a strip current resembles that of a line current, with some smoothing of the sharper features.

PULSE PROPAGATION ON A HORIZONTAL WIRE ABOVE GROUND: FAR-ZONE FIELDS

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Beginning with the classic work of Sommerfeld, there has been a continuing interest in the problem of current elements radiating in the presence of ground. In this paper, we are concerned with the radiation from a semi-infinite horizontal wire above ground when the wire is excited by a transient current pulse.

We begin with an examination of the time history of the pulse for various locations along the wire in order to determine the decay of pulse amplitude and the degradation of pulse rise rate as a function of distance along the wire. We find that the semi-infinite wire has an effective finite length, beyond which the pulse amplitude is negligible.

We next formulate the classic Debye potentials describing an infinitesimal horizontal current element radiating above ground. A linear shift in coordinates, followed by an integration over the semi-infinite wire, yields the general frequency domain potentials. In this paper, we are concerned with the far-fields, which we next obtain by saddle point techniques. Our interest is in observation angles away from grazing and for observation points sufficiently distant that the branch cut contribution, if any, is negligible compared to the contribution from the steepest descent integral close to the saddle point. In addition, we neglect any contribution from the pole on the lower Riemann sheet, since this effect occurs at grazing angles.

Finally, multiplication of the far-field results by the spectrum of the applied current pulse, followed by an inverse Fourier transform, produces the transient far-fields. We include representative results for both time histories and frequency spectra.

TRANSIENT ELECTROMAGNETIC WAVE PROPAGATION ON VIAS OF MULTILAYER INTEGRATED CIRCUIT PACKAGES

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In order to provide shorter interconnects between chips, modern multilayer integrated circuit packages for high-performance mainframe computers employ not only conventional striplines but vertical transmission lines or so-called vias as well. Because vias may be of comparable length with the striplines, the study of transient electromagnetic wave propagation on the former is equally indispensible to the understanding of how fast the multilayer integrated circuits can operate.

In this paper, idealized circuit packages consisting of circular vias going through circular holes in the ground planes that separate different layers of equal thickness are considered. When only one via is present, we show that by treating the layer between two ground planes as a radial waveguide driven by a coaxial feed and making use of symmetry the equivalent network parameters for each layer can be obtained. The multiple layers constitute a periodic structure and presents little difficulty in computing the total transmission matrix. We also study an infinite array of vias and holes with equal spacing along two perpendicular directions. By virtue of the image theory, the problem is reduced to a coaxial transmission line with square outer wall and periodic circular diaphragm discontinuities. Both variational approaches as well as the integral equation method can be applied to the calculation of the characteristic impedance, the junction impedance, and the effective propagation constant. The transient response is then obtained by performing the fast Fourier transform on the frequency domain response or by direct Laplace inversion when the dispersion of junction capacitances is negligible. Our numerical results based on the dimensions of an actual package show that the degree of reflection and signal distortion becomes intolerable when the input rise time is shorter than 500 ps.

TRANSIENT RESPONSE OF A LINE SOURCE OVER A LOSSY EARTH IN THE PRESENCE OF A PERFECTLY CONDUCTING SHIELD

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Previous investigators have given considerable attention to the problem of the transient response of a horizontal line source over a lossy earth. In this paper we consider the effects on the observed far field temporal response when the line source is placed inside of a perfectly conducting structure whose bottom is open to the earth. We consider sources and observers in air only.

The problem is formulated in terms of the frequency domain EFIE, which is solved numerically using moment method techniques. The Green's function for the problem involves Sommerfeld-like integrals which we compute using either numerical integration along the steepest descent path (and branch cut where appropriate) or real axis integration with closed form extraction of the asymptotic form of the integrand. In the far field the integrals are evaluated using an asymptotic analysis of the steepest descent path and branch cut formulation.

After solution of the integral equation over a range of frequencies, we weight with the spectrum of the source current and inverse Fourier transform to obtain the time domain response. Results are presented for a range of observer azimuth angles.

Complex Source Pulsed Beam Propagation and Diffraction

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and

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Abstract

Complex source pulsed beams (CSPB) are transient waveforms generated when the space coordinates and initiation time of a pulsed line source (two-dimensional) or point source (three-dimensional) are assigned complex values. A CSPB is described by the analytic signal obtained from analytic continuation of the conventional time-dependent Green's functions to the complex source domain; the spatial and temporal widths of the pulsed beams are controlled by choice of the source parameters. Generalized CSPB fields can be constructed by convolving the CSPB with various time functions. When the complex source parameter substitution is performed on conventional pulsed Green's functions for a propagation or scattering environment, the resulting transient analytic wave field is the response in that environment to an incident CSPB. This presentation extends and systematizes a previous analysis of the CSPB [E. Heyman and B.Z. Steinberg, J. Opt. Soc. Am.] and it includes interesting examples of generalized CSPB's. CSPB excitation of a wedge, half plane and dielectric interface can be expressed in simple closed forms which permit exploration of phenomena associated with pulsed beam signal diffraction.

INTEGRAL REPRESENTATIONS FOR TRANSIENT ELECTROMAGNETIC FIELDS IN LINEARLY REACTING MEDIA AND THEIR CONVERGENCE

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We consider transient electromagnetic fields $\{\underline{\mathcal{E}}(\underline{r},t), \underline{\mathcal{H}}(\underline{r},t)\}$ in a domain $\mathcal{D}$ surrounded by a surface $\mathcal{S}$. On the surface, we have available successive approximations to the tangential component of one of these fields, which converge in mean square to the corresponding actual tangential field.

For the equivalent free-space frequency-domain problem, it is well known that each approximation corresponds to an exact solution $\{\underline{E}_m(\underline{r},\omega), \underline{H}_m(\underline{r},\omega)\}$ of Maxwell's equations, which inside $\mathcal{D}$ converges pointwise to the actual field $\{\underline{E}(\underline{r},\omega), \underline{H}(\underline{r},\omega)\}$ [Millar, Radio Science 8, 785-796 (1973); Van den Berg and De Hoop, IEEE Trans. GE-22, 42-52 (1984)]. Using a recently derived time-domain reciprocity theorem [De Hoop, Radio Science 22, 1171-1178 (1987)], we generalize this result to time-domain fields in a linearly reacting but otherwise arbitrary medium.

For the special case of a passive medium excited during a time interval of finite length, an even stronger result can be derived. By using energy considerations, it can be shown that the successive approximations $\{\underline{\mathcal{E}}_m(\underline{r},t), \underline{\mathcal{H}}_m(\underline{r},t)\}$ converge in mean square over $\mathcal{D}$, uniformly in time. Possible applications of this result include the truncation of natural-mode representations, and the justification of using surface integral equations for determining fields outside the relevant surface(s).

*Presently on leave at the University of Colorado at Boulder, with the financial support of the Netherlands Organization for the Advancement of Pure Research (Z.W.O.).

Monday PM

URSI-B Session 14

PATCH ANTENNAS

Chairmen: C. A. Balanis, Arizona State University;
K. C. Gupta, University of Colorado

Room: Sheraton Regency A *Time*: 1:25-5:00

ANALYSIS OF A RECTANGULAR MICROSTRIP ANTENNA EXCITED BY A SLOT LINE

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Department of Electrical and Computer Engineering
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The importance of low-cost printed circuit antennas has brought about a continued effort to improve and simplify the analysis of multilayered or stratified media. This paper derives the dyadic Green functions for the electromagnetic fields in a multilayered medium and shows their relationship to the more familiar Green functions for ordinary transmission lines. This approach simplifies the analysis and allows the treatment of an arbitrary number of layers with a minimal increase in effort.

The theory is applied to the analysis of a microstrip antenna fed by a slot line. This configuration is an attractive element for use in active integrated arrays. This new hybrid technology attempts to incorporate active devices such as amplifiers and phase shifters with printed "microstrip" antennas into a single monolithic package. The boundary value problem for the antenna is analyzed in terms of the integral equations for the equivalent electric currents on the patch and magnetic currents representing the slot line. The integral equations are discretized by Galerkin's method and solved on the computer. Techniques designed to enhance the convergence of the spectral domain integrals are described. Important antenna parameters such as the input reflection coefficient are extracted from the solution of the boundary value problem. The problem concerning definition of antenna impedance (which is nonunique) can be avoided by using this technique. Finally, a method for obtaining automated measurements of the antenna reflection coefficient in the guide of interest is developed. Measurements of the reflection coefficient in a slot line feeding a microstrip patch are compared with computer-generated results of the theory.

EFFICIENT ANALYSIS OF STRONGLY COUPLED PATCH ANTENNAS

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Recently, new patch geometries have been proposed in order to increase the bandwidth of microstrip antennas. Using general concepts such as those of log-periodic antennas, microstrip antennas can be formed by a very closely spaced array of patches of various dimensions. However, performance analysis is still very difficult, and no fully satisfactory model exists as yet. Accurate and efficient characterization is crucial for the understanding and development of such relatively wide band antennas on commonly used substrates.

Here we specifically address the problem of closely spaced rectangular patches, although nothing limits the theory to this canonical shape. The approach combines a generalized edge boundary condition (GEBC) developed earlier with a very accurate description of the field in the gap and corner regions. An integral relation relates the horizontal electric field and the vertical magnetic field in the coupling gaps. The fields are then approximated by the product of a gap amplitude, dependent only on a coordinate along the gap, and the transverse quasi-static field distribution. This integral relation is then transformed into a modified GEBC that takes into account the mutual coupling of very closely spaced patches. Special consideration is given to the corner regions where the field evolves from a purely edge distribution to a gap distribution. Finally, the coupled patches are represented by connected networks, and matrix theory is used to compute the input impedance with various feed mechanisms.

The theory will be presented along with a discussion of the numerical efficiency. Comparisons between experimental and theoretical analysis for some typical structures will be given.

SPECTRAL DOMAIN ANALYSIS OF MICROSTRIP PATCH ANTENNAS

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The conventional leaky cavity and transmission line models currently used to analyze microstrip patch antennas, although physically appealing and simple, do not explain the radiation mechanisms of the antenna well. This presentation reappraises the current models and techniques of microstrip antenna analysis in view of this deficiency and develops an alternative approach to determine the radiation.

The integral equations governing the currents on an arbitrarily shaped patch antenna are formulated using a dyadic Green's function approach and then transformed into the spectral domain. These spectral domain equations are in a form suitable for numerical solution with the conjugate gradient-FFT technique. Computer code to implement this has been written for a two dimensional idealization of the general three dimensional problem. This simplified model of a patch antenna consists of a perfectly conducting infinite strip above a dielectric substrate backed by a conducting ground plane and excited from within by a transverse electric current sheet. Once the total current is found on this antenna, the top and bottom surface currents, far zone fields, and radiating aperture admittance of it can also be computed numerically.

Exact simple relations for the far zone fields based on the total current of an arbitrary patch antenna are presented, without introducing the artificial radiating slots traditionally used. Based on results from the two dimensional model, the far zone fields of a thin patch antenna can be reasonably predicted from its bottom surface current alone which can be found with the cavity model. However as the thickness of the substrate or its dielectric constant increases, so does the importance of the top surface current. Numerically computed values for the aperture admittance for various dielectric constants and thicknesses of substrate are also presented and compared with currently available approximate formulas.

THE FIELD AT THE CENTER OF A RECTANGULAR PATCH OF UNIFORM AND LINEAR DISTRIBUTIONS OF CURRENT

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Closed-form formulas for a class of integrals over a rectangle, useful in determining the field at source points of planar current sources are presented. Using these formulas, sufficiently accurate expressions for the field at the center of a rectangular patch of uniform and linear distributions of current are derived. The expressions obtained are particularly useful in integrating the singular part of some commonly used free space and waveguide Green's functions. Computed results verifying the correctness and accuracy of these expressions are presented.

FEED MODELING FOR MICROSTRIP PATCH ANTENNAS

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Microstrip patch antennas are widely used today for many industrial and military applications. There exist several well known approximate techniques to predict parameters such as resonant frequency, bandwidth, and input impedance. These techniques are of varying accuracy, usually obtainable only for a restricted range of parameters, for example: electrically thin substrates or geometries whose solutions are well approximated by the use of one dimensional surface currents. The need exists for a far more accurate and more generally applicable analysis technique.

We will present results from a Galerkin Moment Method type technique of analysis whose accuracy conforms to the inherently narrowband nature of microstrip resonant structures. Our technique is formulated essentially in the spatial domain, but also incorporates spectral domain methods to analytically evaluate the numerically troublesome portion of the self and "near" terms of the impedance matrix. We include the spatial domain dyadic Green's function for non-air dielectrics as well as a two dimensional, subsectional expansion of surface currents. Our concern will be with the modeling of feeding configurations for resonant structures that are representable as rectangular subsections, and in particular, with the feeding of rectangular microstrip patch antennas. The results we present will be for resonant frequency, bandwidth, input impedance, and surface current distributions.

Feed models residing on the patch antenna will be discussed, such as a voltage gap generator (a non-physical source) and an injected current source (corresponding to a coaxial probe feed), as well as microstrip line feeds. The ease, or difficulty, of their numerical implementation will be discussed. Their correspondence to previous theory and measurement (where available) will also be presented.

ARRAY OF RECTANGULAR MICROSTRIP PATCH ANTENNAS FED BY RADIATION COUPLING FOR MILLIMETRE-WAVES

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At microwave frequencies, arrays of microstrip patches exhibit many advantages for conformal antenna applications. In the millimetre-wave range, however, the antennas suffer from high launcher and line losses. Additionally, because of the very small dimensions of the antennas, it becomes more difficult to mount a coaxial line to each element.

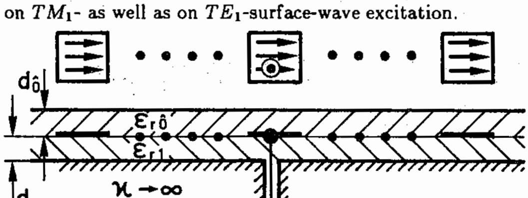
In this paper arrays fed by radiation coupling are investigated. As shown in the figure below, only the central element is fed by a coaxial line. The current on this central element excites a suitable surface wave which propagates to the left and to the right. In order to get a strong coupling a strong surface-wave is required. This is easily achieved for a TM_1-surface-wave if a microstrip antenna with a dielectric cover is used and if the values for the thicknesses and the permittivities of the layers are properly chosen. As the TM-surface-wave mainly propagates in the direction of its exciting current, the patches must be arranged in a line.

Radiation coupling of elements arranged in a column (i.e. perpendicular to the currents on the patches) is achieved by TE-surface-waves. It is possible to excite a TE_1-surface-wave while suppressing the dominant TM_1-surface-wave for suitable sets of $\varepsilon_{r\hat{0}}, \varepsilon_{r1}$ and $d_{\hat{0}}$ with $\varepsilon_{r\hat{0}} > \varepsilon_{r1}$. Then the thickness d_1 is chosen for a strong TE_1-surface-wave excitation and a suitable element pattern.

For the analysis of the array the integral equation for the antenna currents is stated in the spectral domain based on the exact Greens function. The farfield is calculated using the method of steepest descent for the solution of the Sommerfeld integrals. The excitation of the surface waves is determined with the help of the residue theorem.

To begin with, the coupling of two patches is investigated. The results clearly confirm that the coupling is achieved by the chosen surface-wave. Thus it is easy to find suitable parameters e.g. for broadside radiation. If more patches are added, the situation becomes very involved because of the mutual coupling of all elements. Then suitable parameters are only obtained by many numerical experiments. Examples are given for arrays fed by radiation coupling which base on TM_1- as well as on TE_1-surface-wave excitation.

TE_1-Surface-wave coupling



TM_1-Surface-wave coupling

A PROPOSED SMALL, RESONANT, SWEEPABLE ANTENNA

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Dale M. Grimes
Department of Electrical Engineering
The Pennsylvania State University

The work just described [D. M. Grimes, earlier paper] gives hope of a resonant antenna with a small diameter-to-wavelength ratio. A possible implimentation is described. Currents are not excessive and, although narrow band, it is sweepable over a significant frequency range. System design chooses between element sizes and driving current amplitudes. The minimum number of elements needed to achieve resonance, in the usual sense of no reactive power flow, in this type of system is four; superimposed electric and magnetic dipole moments, plus electric and magnetic quadrupole moments. The antenna gain is 9.0 dB. It is independent of frequency and may be increased by introducing higher order matched moment pairs into the system. Since the radiation resistance of small elements is small, very small size ratio antennas may be functional with cryogenic cooling or with microcircuit components.

Theory shows that when superimposed elements are properly phased and driven, the smallest external Gaussian sphere of radius "a", that can be drawn about them, resonates. One implimentation has the electric dipole along the x axis, the electric quadrupole in the x-z plane, the magnetic dipole along the y axis, and the magnetic quadrupole in the y-z plane. To aid in element feeds, half values over a conducting plane are planned for initial tests.

The ratio of magnetic to electric multipolar moments is "c", the ratio of quadrupolar to dipolar coefficients is 10a/9, and all are in phase. Radiation will be transmitted or received along one of the z axes. When phased to transmit in the +z direction it will receive from the -z direction, and vice versa. Since reactive energy is minimized at resonance, once started the Kirchoff sources on the Gaussian surface transmitter may shift with frequency to extract the drive currents needed to remain on resonance across the operational range. In this sense, with flexible sources, the antenna may be adaptive.

Since the reactive energy stored inside a small antenna may be large [V. Badii, K. Tomiyama, D. M. Grimes, preceding paper], a trial and error procedure of optimization is expected. Construction details will be shown.

A PROPOSAL FOR A STANDARD MICROSTRIP ANTENNA AND ITS RADIATION CHARACTERISTICS

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Numerous methods have been developed over the recent years to predict the radiation performance of several microstrip antenna configurations. As a result, many new configurations have been proposed and introduced in the literature.

The open-ring microstrip antenna is proposed to be a standard microstrip antenna. This is because a large number of different shaped antennas can be obtained by changing the gap angle and the annular width. This includes the special cases of quarter, half, three-quarters and ideal gap open-ring (closed-ring with a cross cut) antennas with their limiting case such as their annular's reduction to a circular. It should also be noted that the closed-ring patch can be obtained by ignoring the linear apertures and reducing the gap angle to zero whereas, with large radius of curvature and small sector angle, the rectangular patch can be obtained.

The "Figure of Merit" in terms of Gain-Bandwidth product (M.A. Sultan, IEEE AP-S Int. Symp., 1008-1011, 1987) for the proposed standard microstrip antenna has been determined by utilizing the simple theory based on the cavity model and used to determine its radiation characteristics. This includes the radiation resistance, input impedance at resonance and as a function of frequency, the various type of Q-factor, efficiency, gain, bandwidth and directivity.

Details of this method and its results would be discussed.

COMPUTER CODE FOR THE RIGOROUS ANALYSIS OF MICROSTRIP DISCONTINUITIES AND EMC PATCH ANTENNAS

J.J.Yang* and D.G. Fang
(East China Institute of Technology, Nanjing, China)

This paper describes a computer code for the rigorous analysis of varieties of microstrip antennas and discontinuities by using the exact image theory of layered medium. In this code, the overall module of the microstrip transmission line, its excitation and the microstrip patch of arbitrary shape are treated as a radiating system. The mixed potential integral equation is resolved by a two dimensional moment method using subsectional basis functions. The analytical forms of space domain Green's functions have involved all the substrate and cover effects. This code can provide the results of current distribution on the feeding line and the radiating patch for any dielectric substrate at any frequency, from which, the propagation constant β and the characteristic impedance Zo of a microstrip line with or without the dielectric cover, the input impedance and the radiation pattern of the EMC microstrip patch antenna , and the equivalent network parameters of the microstrip discontinuities (e.g.: open end, gap, T-junction, coupled line end) can be obtained. The procedure is outlined as follows:

1. For a given substrate thickness , a relative dielectric constant and an operating frequency, find the exact images of a horizontal electric dipole embedded in the substrate by using the combination of Prony's method and nonlinear optimization technique, that is, to find the analytical forms of Green's functions.
2. For the "basic disposition" of conductors, find the impedance matrix and store it as a data package.
3. Input the coordinates of the treated radiating patch and feeding line. Then, "sieve" the data package to form the impedance matrix of that disposition of conductors.
4. Inverse the above matrix to find the current distribution and other electromagnetic quantities.
5. Vary the frequency or the relative dielectric constant, repeat steps 1-4.

Numerical results will be presented at the meeting.

Monday PM

Joint AP-S, URSI-B Session 16

SPECIAL SESSION ON ITERATIVE METHODS

Chairmen: E. Miller, Rockwell; R. Kleinman, University of Delaware

Organizer: R. Kleinman, University of Delaware

Room: Sheraton Regency C *Time*: 1:25-5:00

1:30	**The Basic Difference Between Solving an Operator Equation and a Matrix Equation by the Conjugate Gradient** T. K. Sarkar, Syracuse University	See AP-S Dig.
2:10	**"To Iterate or Not?" That's the Question!** R. Mittra, University of Illinois	See AP-S Dig.
2:50	**COFFEE BREAK**	
3:20	**Comparison of Convergence Rates of the Conjugate Gradient Method Applied to Various Integral Equation Formulations** J. E. Wheeler, D. R. Wilton, University of Houston	See AP-S Dig.
4:00	**Iterative Methods for First-Kind Integral Equations of Convolution Type** P. M. van den Berg, Delft University of Technology; R. E. Kleinman, University of Delaware	See AP-S Dig.
4:40	**Discussion**	

Notes

Monday PM

URSI-F Session 17

RANDOM ROUGH SURFACE & VOLUMETRIC SCATTERING

Chairmen: A. Ishimaru, University of Washington;
D. De Zutter, University of Ghent

Room: Sheraton Comstock A *Time*: 1:25-5:00

ROUGH SURFACE INCOHERENT BACKSCATTERING OF SPHERICAL WAVE

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The spherical electromagnetic wave backscattering from a random rough terrain is investigated. The incoherent backscattered power is computed to examine how the antenna beamwidth and wave sphericity influence the magnitude of co-polarized terrain radar backscattering. The one-dimensional random rough surface in the Kirchhoff approximation is invoked to model a rough terrain. Incident and scattered wave phase fronts are assumed to be spherical, and the effects of antenna beamwidth and wave sphericity are accounted for in radar backscattering coefficient computation. It is found that incoherent backscattering power strongly depends upon the antenna beamwidth and wave sphericity, in case the air/satellite borne SAR imaging radar operates at L-band or lower frequencies.

A SLIGHTLY RANDOM ROUGH SURFACE - HOW GOOD CONSERVE ENERGY?

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Abstract

The energy conservation characteristics of slightly - perturbed rough surface are examined. Based on the small perturbation technique of Rayleigh-Rice method, the scattered fields up to the second order in surface height deviation are examined. The reflectivity of the perfectly conducting random rough surface is computed for both horizontally and vertically polarized incident waves, and examined how good the law of energy conservation may be satisfied. The range of applicability of the Rayleigh-Rice method is investigated in terms of surface roughness structure parameters (surface height correlation length and standard deviation) and incidence angles.

THREE-LAYER RANDOM MEDIUM MODEL FOR POLARIMETRIC REMOTE SENSING OF EARTH TERRAIN

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A three-layer random medium model is developed to study the fully polarimetric scattering properties of earth terrain. The top layer is modeled as an isotropic random medium, the middle layer as an anisotropic random medium, and the bottom layer as a homogeneous half-space. Volume scattering effects of both random media are characterized by correlation functions in which variances and correlation lengths describe strengths of permittivity fluctuations and physical sizes of embedded inhomogeneities, respectively. The anisotropic effect of the middle layer is attributed to specific structure and alignment of the scatterers. With the strong fluctuation theory, the mean fields in the random media are derived under the bilocal approximation with singularities of the dyadic Green's functions properly taken into consideration. With the discrete scatterer concept, effective permittivities of the random media are calculated by two-phase mixing formulas. Then, the distorted Born approximation is used to calculate the covariance matrix which describes the fully polarimetric scattering properties of the terrain and is used in radar image simulation and earth terrain identification and classification.

A two-layer random medium model has been successfully applied to polarimetric remote sensing of earth terrain such as vegetation, meadow, and ice layer. The results obtained with the three-layer configuration have the capability of accounting for polarimetric scattering from earth terrain under the effects of weather, seasonal variation, and atmospheric conditions such as forest under mist, meadow under fog, and ice under snow. The effects on polarimetric wave scattering due to the top layer are identified by comparing the three-layer model results with those obtained from the two-layer model. The enhancement of the radar returns due to dry-snow cover on top of first-year sea ice observed in the experimental data can be explained using the three-layer random medium model. The theoretical results are illustrated by comparing the calculated covariance matrices with the polarimetric measurement data.

THEORETICAL MODEL FOR SNOW-COVERED SEA ICE

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A three-layer random medium model is developed to investigate effects of snow cover on the sea ice signature for microwave remote sensing. The volume scattering and anisotropic effects due to embedded inhomogeneities in the snow-covered sec ice are studied with the wave theory. The snow layer is modelled as an isotropic random medium and the sea ice as an anisotropic random medium. Volume scattering effects are caused by granular ice particles and water contents in snow and by brine inclusions and air bubbles in sea ice, respectively. The anisotropic effect is attributed to the elongated structure of brine inclusions with a preferred alignment between ice platelets. In the random medium model, the essential quantity is the correlation function which contains important physical parameters such as variances and correlation lengths for characterizing the strength of the permittivity fluctuation, the physical size, and the geometrical structure of scatterers. We have extracted correlation function from digitized image of saline ice sample grown in the outdoor tank at CRREL. The calculated correlation lengths are consistent with reported average size of brine pockets.

The strong fluctuation theory is applied to account for the distinct permittivity difference between air, ice particles, water, and brine inclusions. First of all, singularities of the dyadic Green's functions for snow and sea ice are properly considered. Then, the mean fields in both media are derived by the bilocal approximation. With the discrete scatterer concept, effective permittivities for dry snow and first-year sea ice are computed by two-phase mixing formulas. The effective permittivities of sea ice calculated as a function of fractional volume of brine inclusions are found to be consistent with the published results obtained from slab ice samples. For calculating effective permittivities of wet snow and multi-year sea ice, three-phase mixing formulas are used since wet snow consists of air, ice grains, and water and multi-year sea ice is composed of pure ice, brine inclusions, and air bubbles. Finally, the bistatic scattering and backscattering coefficients are computed with the distorted Born approximation. The results are illustrated by comparing the backscattering coefficients as a function of incident angle with experimental data from controlled field measurements.

SNOW BACKSCATTER CHARACTERISTICS AT 215 GHZ

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The University of Massachusetts has constructed a 215 GHz High-Power (60 W) Pulsed Radar System that is capable of making scattering measurements up to several kilometers range (R.M. Narayanan et al., URSI Comm. F Symp. Proc., Ann Arbor, MI, May 1987). The radar uses state-of-the art designs for both the transmitter and receiver functions, and employs a dedicated data acquisition system allowing backscatter measurements of distributed targets with 15 meters resolution.

Measurements of backscatter characteristics of snow at 215 GHz were made at incidence angles of 39°, 70.5°, 83.2° and 86.5° during February-March 1987. It was found that at near-grazing incidence, cross-polarized backscatter was very close (within 5 dB) to the co-polarized value for dry frozen snow. However, data for wet snow at 70.5° incidence showed less depolarization.

Statistical analysis of 104 points of VV data at 70.5° incidence yielded a close fit to a Rayleigh distribution for the amplitude of the backscattered signal by comparing computed values of the first four moments to the theoretical values. It was also inferred that this distribution may be valid at other incidence angles, although fewer points were available for statistical analysis.

EFFECTIVE PERMITTIVITY OF MIXTURES WITH INHOMOGENEOUS SCATTERERS: CONTINUOUS RADIAL PERMITTIVITY PROFILE

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Calculation of the effective macroscopic permittivity of dielectric mixtures has received considerable interest recently. The theories presented normally treat one constituent material in the mixture as a background and the other components add polarization to the total displacement. The cases of mixtures with ellipsoidally shaped homogeneous scatterers have been solved, and these mixtures can be two-phase or multiphase; the restriction only being the homogeneity of each single scatterer. Also the case of scatterers as multilayer spheres has been solved. The effective permittivity is a low-frequency quantity: it only applies for cases where the spatial correlation function of the mixture is smaller than the wavelength.

In this presentation, the case of mixtures with spherical scatterers that possess arbitrary continuous permittivity profile will be given solution. The only restriction is that the permittivity must be a function of the distance from the center of the scatterer, i.e., $\epsilon(\mathbf{r}) = \epsilon(r)$. In order to be able to calculate the polarizability induced in the scatterer, actually the solution of Laplace equation is needed. However, generalizing the case of multilayer spheres where the fields can be decomposed into a constant part and a dipole type contribution part, a differential equation can be derived for the continuous case. It can be shown that the dipole type field contributes nothing to the polarizability. Only the constant part (a so called $C(r)$-function) is needed.

The effective permittivity is defined as the ratio between the overall displacement and the macroscopic field. The average polarization has to be calculated by adding all dipole moments of the scatterers in a unit volume. The dipole moment of one scatterer is reached by integrating the differential dipole moment over the variable which is the radius. The differential dipole moment consists of the product of a volume, which is a spherical shell, the permittivity difference with respect to the background medium, and the $C(r)$-function, that is solved from the differential equation for a given ϵ-profile. Solutions for permittivity profiles (linear, parabolic, exponential) will be given.

Wave Propagation in a Random Particulate Medium: Fractal Size Distribution

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Fractals in electrical engineering have begun to come of age: diffraction by fractal phase screens is being energetically investigated, and fractal arrays are being toyed with by antenna designers. Much to be desired is the examination of wave propagation in fractal particulate media, and here we report our preliminary investigations.

We consider a discrete medium consisting of a not dense collection of particles of identical shapes and constitution, but possessing a bounded size distribution obeying a power law. Let ζ be a typical dimension of the scatterers, and $n(\zeta)$ be the number density of particles of size ζ in a unit volume. The power law is given by

$$n(\zeta) = 0, \quad \zeta < \zeta_o,$$

$$n(\zeta) = a\,\zeta^b, \quad \zeta_o \le \zeta \le \zeta_1,$$

$$n(\zeta) = 0, \quad \zeta > \zeta_1,$$

where ζ_o and ζ_1, respectively, are the lower and the upper bounds on the particle size, while a and b represent the fractal distribution. The effective properties of such a medium, in relation to those of the host and the inclusions, will be investigated as functions of the distribution parameters a and b. To that end we will use a self-consistent multiple scattering theory based on the T-matrix method. Relevant examples from nature will be given.

Anomalies in the Temperature - Dependent Effective Properties of Porous Media

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In industrial practice it is common to heat porous ceramics to very high temperatures in order to achieve compaction; this process is called sintering. There has been considerable interest recently in using microwaves for this purpose. Microwave sintering of ceramics offers several advantages over sintering using conventional furnaces because of substantial reduction in sintering time as well enhanced energy efficiency. Furthermore, due to the rapid heating during microwave sintering, the segregation of impurities at the grain boundaries is minimized.

In this context, we examined the effective temperature-dependent properties of porous ceramics. The effective dielectric constants were computed at several microwave irradiation frequencies using a self-consistent multiple scattering formalism based on the T-matrix method. The resulting Cole-Cole plots showed an interesting anomaly. For some frequency range, depending upon the ceramic material and its porosity, the imaginary part of the effective dielectric constant almost vanished as the temperature was increased. Further increase of temperature, however, resulted in increasingly higher values of the imaginary part of the effective dielectric constant. Our paper is based upon a thorough investigation of this remarkable anomaly, and shall bear upon the optimization of the pre-sintering temperature as well as upon that of the utilizable frequencies for given initial grain size.

EFFECTIVE PROPAGATION CONSTANTS FOR DENSE NONTENUOUS MEDIA WITH MULTI-SPECIES OF PARTICLES

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and
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In a dense medium, the particles occupy an appreciable fractional volume. In a nontenuous medium, the dielectric properties of the particles are substantially different from that of the background medium. In recent years, studies have been made on the propagation and scattering of waves in dense nontenuous media with applications to geophysical terrain such as snow, ice-covered land, soil, and vegetation.

The quasicrystalline approximation (QCA) has been applied to study the first moment of the field in a dense nontenuous scattering medium. The quasicrystalline approximation with coherent potential (QCA-CP) generally yields results that are substantially different from those of QCA for dense nontenuous media. It has also been shown that QCA-CP is energetically consistent with the ladder approximation modified with the pair-distribution function while QCA is not.

All previous studies of dense nontenuous media assume that the particles are identical in size and shape. In this paper we consider dense nontenuous media with multiple species of particles. The multiple species refers to the fact that the medium is a mixture of particles with different sizes and permittivities. This is important in the application of discrete random media theory to remote sensing because in geophysical media the particles are not of a single size and generally obey a size distribution. Moreover, geophysical media are often mixtures of substances with different permittivities. For example, wet snow consists of water droplets besides ice particles. We have calculated the effective propagation constants in such dense nontenuous media. The derivation is based on both QCA and QCA-CP. The pair-distribution functions for multi-species particles are calculated. In the low frequency limit, analytic closed form expressions are obtained for the complex effective propagation constants. Numerical results of the effective propagation constants are illustrated as a function of particle sizes, fractional volumes, and permittivities.

URSI: Random Media - Commission B or F

Monday PM

URSI-B Session 18

INVERSE SCATTERING AND IMAGING

Chairmen: P. Banerjee, Syracuse University;
D. Jaggard, University of Pennsylvania

Room: Sheraton Comstock B *Time*: 1:25-5:00

1:30	**Imaging of Lossy Surface-Impedance Objects** C. Shimos, D. L. Jaggard, University of Pennsylvania	102
1:50	**A Microwave Imaging Technique for Determining the Internal Scattering Centers of Cavity Structures** R. Chou, W. D. Burnside, Ohio State Univ.	103
2:10	**Microwave Imaging Through Randomly Distributed Spherical Particles** M. J. Sierman, Y. Kuga, A. Ishimaru, University of Washington	104
2:30	**Generalized Radiometry of Partially Coherent Wavefields Radiated from Two and Three-Dimensional Spatially Incoherent Sources** A. J. Devaney, Northeastern University	105
2:50	**COFFEE BREAK**	
3:20	**The Inverse Source Problem of Magnetostatics** A. Sezginer, Schlumberger-Doll Research	106
3:40	**Time-Domain Approach for One-Dimensional Inverse Scattering Using a Nonlinear Renormalization Technique** Y. Kim, New Jersey Inst. of Tech.; D. L. Jaggard, Univ. of Pennsylvania; N. Y. Cho, G. M. Whitman, New Jersey Inst. of Tech.	107
4:00	**Accurate Reconstruction of One and Two-Dimensional Targets Using the FD-TD/Feedback Method** M. Strickel, A. Taflove, Northwestern Univ.	108
4:20	**Time Domain Electromagnetic Imaging** M. Yu, D. Lin, D. Lu, Tsinghua University	109
4:40	**Determination of Target Scattering Center by Time-Domain Scattering Range Technique** B. Qiang, Y. Shi, Northwest Telecommunications Eng. Institute	110

IMAGING OF LOSSY SURFACE-IMPEDANCE OBJECTS

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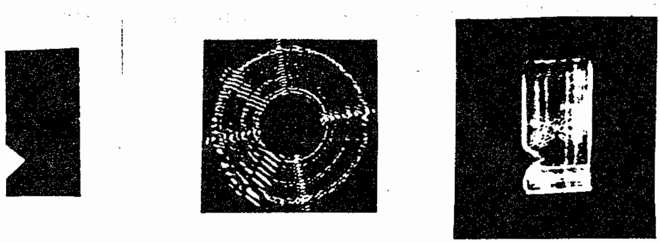
The use of swept-frequency microwaves has been successfully used both for conducting [see, e.g., N. H. Farhat, C. L. Werner and T. H. Chu, *Radio Sci. 19*, 1347 (1984)] and dielectric objects [see, e.g., K. I. Schultz and D. L. Jaggard, *J. Opt. Soc. A4*, 1773 (1987)]. In the former, surface topology has been recovered from remote measurements while in the latter, surface and internal structure can be found. Here, we examine the use of these techniques for an intermediate case, the reconstruction of lossy objects characterized by the surface-impedance boundary condition.

In this presentation we show the mathematical formulation of the theory which is the analogue to the physical optics or Born approximation in the perfectly conducting and lossless cases, respectively. Experiments using swept-frequency microwave illumination for backscatter measurements over all aspects in a plane, yields the desired reconstructions. That is, bandlimited projection images can be reconstructed from experimental data in accordance with theory. Shown below is a photograph of a desired surface-impedance object (left). The backscatter amplitude data for 360° aspect angles from 6 to 17 GHz. is displayed (center) and shows the characteristic streaks perpendicular to each flat surface of the object due to specular reflection. Finally, the bandlimited microwave projection image (right) is shown to be a reasonable reproduction of the original object.



† Also, Astro Space Division, General Electric Co., Valley Forge, PA.

A MICROWAVE IMAGING TECHNIQUE FOR DETERMINING THE INTERNAL SCATTERING CENTERS OF CAVITY STRUCTURES

R. Chou and W. D. Burnside
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For electrically large structures, the main contributions to electromagnetic scattering tends to be concentrated at specific localized areas, known as scattering centers. Knowledge of a scattering center is essential to the study of its radar cross section (RCS) reduction. Much work has been done in the area of isolating the scattering centers from external structures (A. K. Dominek, et. al., *IEEE Trans. Antennas Propagat.*, vol AP-35, 305-312, 1987 and its included references). However, there is no method for extracting the internal scattering centers from a complex cavity structure.

By applying a method similar to that used for external structures (D. L. Mensa, Pacific Missile Test Center Technical Publication TP-81-08, 1981), high resolution microwave images of the internal scattering centers from cavities can be obtained. By combining both pulse compression and synthetic aperture processing of signals reflected from rotating targets, resolution can be obtained in range and cross range. Both the pulse compression and the synthetic aperture processing are accomplished by fast Fourier transform (FFT) algorithms.

MICROWAVE IMAGING THROUGH RANDOMLY DISTRIBUTED SPHERICAL PARTICLES

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Microwave imaging techniques, which involve measuring backscattered fields from a conducting target illuminated with a frequency swept source over different aspects, are used to form images of a metalized jet model through random media. The effect of a random media on the imaging process is examined by positioning randomly distributed glass beads imbedded in thin styrofoam sheets in various densities between the target and the transmit and receive antennas. The size parameter ka for the media, where k is the wave number and a is the average radius of the particles, ranged from 0.5 to 1.1 for the frequency band of 8 GHz to 18 GHz. The optical depth τ of the media was varied from approximately 0.18 to 1.8. Experimental results of the images made through the random media are presented. The main effect of the random media is seen to be a reduction in signal-to-noise ratio and that phase information through the media is being preserved.

URSI: Random Media - Commission B

GENERALIZED RADIOMETRY OF PARTIALLY COHERENT WAVEFIELDS RADIATED FROM TWO AND THREE-DIMENSIONAL SPATIALLY INCOHERENT SOURCES

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The generalized theory of radiometry introduced by Walther [A. Walther, *J. Opt. Soc. Am.*, **58**, p.1256 (1968) and **63**, p. 1622 (1973)] is used to compute the radiance function (specific intensity) for the radiation emitted from two and three-dimensional spatially incoherent primary sources. A radiative transfer equation is derived for the radiance function which is shown to be a generalization of an equation first obtained by Zubary and Wolf [*Optics Commun.*, **20**, p.321 (1977)] for the radiance function of statistically homogeneous free fields in in vacumn. This equation is shown to reduce in the short wavelength limit to the classical equation of radiative transfer and is used to establish the result that Walther's radiance function for extended spatially incoherent sources reduces to the classical specific intensity in the short wavelength limit. This latter conclusion is a generalization of a recent result obtained by Foley and Wolf [*Optics Commun.*, **55**, p.236 (1985)] who showed that Walther's generalized radiance for planar two-dimensional incoherent sources reduces to the classical radiance in the limit of zero wavelength.

An integral representation for the radiance function is presented and used to compute the radiance for a number of two-dimensional model sources. The radiance from these model sources is studied in computer simulations as a function of distance from the primary source, wavelength and viewing angle. A detailed comparison of the radiance function so computed and the classical specfic intensity generated by these sources is performed and it is found that except in the very near field of the primary source the classical specific intensity is a poor approximation to Walther's radiance function. From this it is concluded that classical radiometry and radiative transfer theory do not adequately represent energy transfer from primary sources except in the very near field of the sources.

THE INVERSE SOURCE PROBLEM OF MAGNETOSTATICS

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The problem of retrieving a static current density from the knowledge of the magnetic field it produces at a plane is solved. This problem does not have a unique solution. However, there is a unique solution of the least L_2 norm (A. Sezginer, Inverse Problems **3**(1987)L87-L97). If the 2-dimensional spatial Fourier transform of the magnetic field that is measured on the plane $z = 0$ is $\mathbf{H}(\mathbf{k}_\perp)$, then the 3-dimensional Fourier transform of the volume current distribution of the least L_2 norm is

$$\mathbf{J}(\mathbf{k}) = \frac{2\,\|\mathbf{k}_\perp\|\; i\mathbf{k} \times \left(\overleftrightarrow{\mathbf{D}} \cdot \mathbf{H}(\mathbf{k}_\perp)\right)}{\pi\,\|\mathbf{k}\|^2}$$

$$\overleftrightarrow{\mathbf{D}}(\mathbf{k}_\perp) = \mathbf{u}_1\mathbf{u}_1 + \frac{1}{2}\mathbf{u}_2\mathbf{u}_2 + \mathbf{e}_z\mathbf{e}_z$$

$$\mathbf{u}_1 = \mathbf{k}_\perp / \|\mathbf{k}_\perp\|$$

$$\mathbf{u}_2 = \mathbf{e}_z \times \mathbf{u}_1$$

$$\mathbf{k}_\perp = \left(\overleftrightarrow{\mathbf{I}} - \mathbf{e}_z\mathbf{e}_z\right) \cdot \mathbf{k}$$

The minimum norm current distribution is a filtered version of any other current distribution that produces the same magnetic field data. The kernel of the filter is obtained in closed form. The resolution of the least norm inverse is found analytically and it is illustrated by graphics. The resolution in the transverse direction (parallel to the measurement plane) is proportional to the depth of investigation (distance from the measurement plane). There is no resolution in the direction perpendicular to the measurement plane.

TIME-DOMAIN APPROACH FOR ONE-DIMENSIONAL INVERSE SCATTERING USING A NONLINEAR RENORMALIZATION TECHNIQUE

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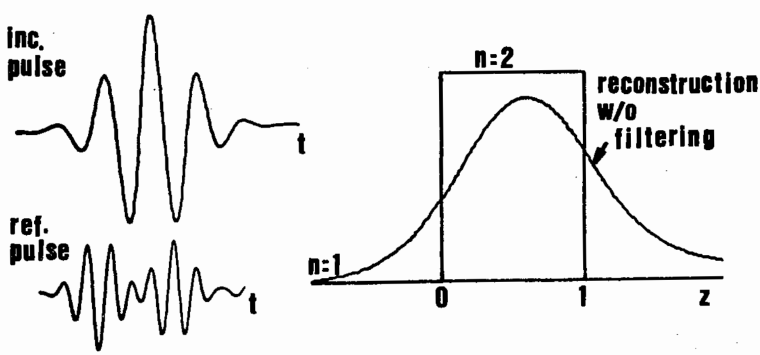
One-dimensional inverse scattering problem is concerned with the reconstruction of electrical characteristics of a stratified medium through the knowledge of incident and reflected waves. An approximate but accurate spectral-domain solution has been developed using a nonlinear renormalization technique based on the inversion of the Riccati equation (D. L. Jaggard and Y. Kim, JOSA A, V2, 1922-1930, 1985). In this presentation, a time-domain solution and its related features are discussed.

Here, a modulated Gaussian pulse is used as an incident wave as shown below. As the variance of the Gaussian pulse becomes large, it is clear that the resolution size of the reconstructed profile also becomes large. In order to improve the resolution of the reconstruction, a deconvolution procedure is applied to the reconstruction algorithm using a spectral-domain filter. The robustness of the algorithm is tested under various types of noises. Displayed below is the reconstruction of a homogeneous slab.



ACCURATE RECONSTRUCTION OF ONE AND TWO-DIMENSIONAL TARGETS USING THE FD-TD/FEEDBACK METHOD

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This report introduces a new time-domain electromagnetic inverse scattering algorithm that uses a finite-difference time-domain (FD-TD) forward scattering representation in a numerical feedback loop with a nonlinear optimization routine. This algorithm is used to simultaneously reconstruct the permittivity and conductivity profiles of one and two-dimensional targets assuming a priori knowledge of the shape and location of the target.

An important feature of our algorithm is its ability to reconstruct dispersive media, that is, media in which the permittivity and conductivity vary with frequency. This is achieved by illuminating the target with a narrow band incident pulse and then using the entire backscattered pulse to simultaneously reconstruct the entire target.

The reconstruction of the permittivity and conductivity profiles of the target is formulated as a curve fitting problem. We are given m discrete data values $E_1, E_2, \ldots, E_m$ for the scattered electric field for m values of time. The permittivity and conductivity profiles of the target are represented by parametric approximating functions, $\varphi_p(a)$ and $\varphi_c(b)$, which have a total of n adjustable parameters ($n \leq m$) chosen to minimize the function

$$f(a,b) = \sum_{i=1}^{m} [r_i(a,b)]^2$$

where

$$r_i(a,b) = \text{FD-TD}\left[\, t_i, \varphi_p(a), \varphi_c(b) \,\right] - E_i \qquad i=1,2,\ldots,m$$

Time Domain Electromagnetic Imaging

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After reviewing the definition of the IMAGE, We definite the meaning of ELECTROMAGNETIC IMAGING and discuss the difference between electromagnetic imaging and optical imaging. The basic principle of time domain eletromagnetic imaging is outlined. We use synthetic aperture and narrow pulse ranging method to achieve high resolving capability in both azimuth and range direction. We have shown that from a set of time domain response obtained from different viewing position, electromagnetic image of objects can be reconstructed. We use an impulse signal as wide band excitation and its pulse width is less than 1 ns. Two receiving antennas for noise reduction are used. The imaging system has a good response shape and the shout impulse has an advantage of leaving a clear time window. Many signal processing techniques such as digitalizing, filtering are used. The paper presents experimental results in free space for demonstrating high resolution capability of the imaging method. We have reconstructed the image of one metallic cylinder with 15cm diameter and two of the same cylinder spatially separated 60cm. The authors also point out that this method can be used to locate and discriminate underground objects under the condition of high signal noise ratio.

DETERMINATION OF TARGET SCATTERING CENTER BY TIME-DOMAIN SCATTERING RANGE TECHNIQUE

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Target scattering center can be determined by time domain scattering range technique. To determine the scattering center as simple as possible, the model based on Tauberian approximation is established, and the model based on the models of scattering center, we can use the improved frequency domain Prony's method to extract the location and amplitude of scattering center from measured smooth impulse response. The problem to determine the number of scattering centers is also considered, which is equivalent to determining the order of Prony's equation. This problem can be solved by the eigenvalue method and singular value decomposition method which are applicable to noisefree data and noisy data. The determination of sphere target scattering centers is simulated, and an experiment is also made on it. A Gassian pulse of about 100v in amplitude and 1.3ns in width generated by an avalanche triode impulse generator is shown in FIG.1, and the measured and pre-processing smooth response of a 30cm diameter conductive sphere from the acquisition and pre-processing system is shown in FIG.2, the result processed by Prony's method is shown in Table-I.

TABLE-I

No.	Relative Location (m)		Relative Amplitude (model)	Note
	Re.	Im.		
1.	-.9412e-2	-.1679e+1	.7046	Creeping wave
2.	-.5360e-2	-.8509	.8385	Specular point

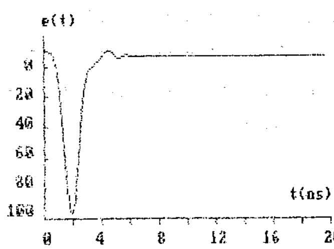

FIG.1

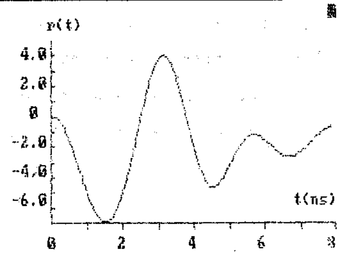

FIG.2

Monday PM

Joint AP-S, URSI-B Session 20

ELECTROMAGNETIC THEORY I

Chairmen: S. Strom, Royal Inst. of Tech.; S. Adachi, Tohoku University

Room: Schine 304C *Time*: 1:25-5:00

1:30	**A Uniqueness Theorem Used in Showing The Equivalency of Integral Equation and Maxwell Equation Formulations of Electromagnetic Integration Problems** S. Li, Trenton State College	See AP-S Dig.
1:50	**Solutions of Maxwell Equations by Matrix Formulation** F. C. Chang, TRW Electronic Systems Group	See AP-S Dig.
2:10	**A Maximum Entropy Solution for The Underdetermined Electromagnetic Field Within a Volume.** R. M. Bevensee, Lawrence Livermore National Laboratory	See AP-S Dig.
2:30	**Addition Theorems For Electromagnetic Wave Scattering by Spheroids Of Arbitrary Orientation** M. F. Cooray, I. R. Ciric, The University of Manitoba	See AP-S Dig.
2:50	**COFFEE BREAK**	
3:20	**A Periodic Source Function** J. Nachamkin, B. Compani-Tabrizi, Lockheed	See AP-S Dig.
3:40	**Numerical Analysis of Smith-Purcell Radiation by a Relativistic Electron Beam Propagating Parallel to a Reflection Grating** K. Yasumoto, T. Tanaka, T. Aramaki, Kyushu University	See AP-S Dig.
4:00	**Are There Physical Size Limitations on Directional Antennas?** D. M. Grimes, The Pennsylvania State University	112
4:20	**The Methodology of Boundary Methods** W. Zhang, Nanjing Institute of Technology	See AP-S Dig.
4:40	**Eigenfunction Expansion of the Dyadic Green's Functions in Spherical Coordinates** S. Pan, Shanghai University	See AP-S Dig.

ARE THERE PHYSICAL SIZE LIMITATIONS ON DIRECTIONAL ANTENNAS?

Dale M. Grimes

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The Pennsylvania State University

A linear antenna's diameter-to-wavelength ratio primarily determines the phase difference between the driving voltage and current, zero at resonance and nearing 90° for small ratios. The radiation pattern and the driving impedance are, respectively, weak and strong functions of the same ratio. Many have tried unsuccessfully to make small ratio, efficient antennas. Chu [L. J. Chu, J. Appl. Phys. 19, 1168-1175, 1948], using a multipolar field expansion, considered radiation passing through the smallest possible external Gaussian sphere about the antenna. He used the complex Poynting vector to find power through the surface, analyzed radiation properties mode by mode, and showed that small resonant radiators are narrowband and support large current densities. The effect increases so rapidly with decreasing size ratio that there is little reason to pursue the subject further.

His work, however, may not be general. As a thought experiment, consider a small receiving antenna extracting a signal from a plane wave [D. M. Grimes, J. Math. Phys. 23., 897-914, 1982]. It does not support excessive currents and is not especially narrow band. Yet keeping modal current magnitudes constant and reversing appropriate phases to switch incoming into outgoing waves changes the antenna from a receiver to a radiator of directed power.

Chu used an incomplete field expansion. The full expansion and the correct reactive power form were given elsewhere [D. M. Grimes, Physica 20D, 285-302, 1986]. It shows results the same as Chu's for linear electric multipoles, as will be discussed [V. Badii, K. Tomiyama, D. M. Grimes, next paper]. More complex cases are starkly different, primarily because modal reactive powers are not orthogonal. Intermodal field terms may even dominate. The correct reactive power expression contains roots at which the Gaussian sphere, regardless of its diameter-to-wavelength ratio, resonates. Modal driving current magnitude may be linearly exchanged for physical size, as will be discussed [C. A. Grimes and D. M. Grimes, following paper].

Conditions necessary for such a circumstance are outlined.

Monday PM

Joint AP-S, URSI-B Session 21

ANTENNA MEASUREMENTS

Chairmen: E. S. Gillespie, University of California;
D. W. Griffin, University of Adelaide

Room: Newhouse A1 *Time*: 1:25-5:00

1:30	**Time-Domain Techniques For The Measurement Of Narrow-Bandwidth Antenna Parameters** E. N. Clouston, S. Evans, Cambridge University	See AP-S Dig.
1:50	**A Triplate Stripline Slot Antenna Developed For Time-Domain Measurements On Phased Arrays** E. N. Clouston, S. Evans, Cambridge University	See AP-S Dig.
2:10	**The Measurement of Attenuation Along the Arms of a Travelling Wave V-Antenna** E. J. May, University of Exeter; I. R. Bin-Ghunaim, Ministry of Post, Saudi Arabia	See AP-S Dig.
2:30	**A Fundamental Source of Error in the Scattering Method of Measuring Antenna Surface Field Distributions** D. W. Griffin, The University of Adelaide	See AP-S Dig.
2:50	**COFFEE BREAK**	
3:20	**Radiation Efficiency Measurement Method For Electrically Small Antennas Using Radio Wave Scatterers** T. Maeda, T. Morooka, Toshiba Research and Development Center	See AP-S Dig.
3:40	**Adaptive Array Near-Field Measurements Using The Fresnel Transform Approximation** W. J. Graham	114
4:00	**The Effect of Field Scanning Probe on Test Range Evaluation** A. Fer, Purdue U. School of Eng. & Tech. At Indianapolis	115
4:20	**Rapid Near-Field Antenna and RCS Measurements Via Probe Arrays** B. J. Cown, J. P. Estrada, M. E. Cram, Georgia Inst. of Tech.; J. C. Bolomey, D. Picard, G. Fine, M. Mostafavi, L. Jofre, LSS-SUPELEC	116
4:40	**Measurement of Vertical Radiation Patterns of OTH Radar Antenna Array using a Tethered Aerostat** L. Xia, Nanjing Research Institute	See AP-S Dig.

ADAPTIVE ARRAY NEAR-FIELD MEASUREMENTS USING THE FRESNEL TRANSFORM APPROXIMATION

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Antenna measurement on an outdoor far-field range is fraught with difficulties for adaptive arrays. The convential far-field distance requirement may be doubled, tripled, or more for low sidelobe antennas. This requirement is even more severe for an adaptive array due to null filling. Multipath on an outdoor range is a source of error in direction of arrival estimation. Finally, measurement and simulation of an adaptive array antenna requires the placement and mobility of multiple jammers and targets at all angles in its field of view. Thus far-field measurements are often difficult and unreliable for low sidelobe antennas or adaptive arrays.

For an adaptive array there are problems with conventional near-field measurement techniques. First, the array must adapt its pattern in the presence of one or more simulated jammers. However since these jammers are located in the near-field of the array, the wavefront from each source will be spherical. When the array adaptive beamforming network computes the weights to null the jammer, the jammer will be nulled in the near-field (to the extent that the adaptive array can form an accurate null), but these weights will be incorrect for nulling the plane wave from a far-field source. Subsequent computation of the far-field pattern from conventional near-field measurements of the adapted array will then show an imperfect null and the degree of imperfection due to the adaptive beamforming algorithm itself cannot be determined.

This paper examines the use of the Fresnel transform approximation to, in effect, make planar the spherical wavefronts from near-field jammers, so that they appear to be located in the far-field when the array is focused at the near-field range of the jammers. For adaptive arrays, an important advantage of the FTA becomes apparent when the array is focused at a range in its Fresnel region. It is seen that the angular pattern at the focal radius is proportional to the angular far-field pattern multiplied by a quadratic angular phase factor at both small and wide angles. Thus, the FTA may be a useful method for determining the far-field pattern of an adaptive array from near-field measurements.

THE EFFECT OF FIELD SCANNING PROBE ON TEST RANGE EVALUATION

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After all possible measures have been taken to minimize reflection problems, the range must be calibrated by observation of the variation in amplitude of the field on the test aperture, indicating departure from plane wave conditions in horizontal and vertical polarizations. In this paper the level of confidence over a given angular span is shown to be proportional to the beam width of the probe. The relationship between probe output and the extraneous signal interference for the case with single extraneous plane wave field E_r, in addition to the direct field E_d resulting in cyclic perturbations is

$$E_r/E_d\ (\text{dB}) = 20 \log\left[\frac{\text{antilog}\ (\sigma/20)-1}{\text{antilog}\ (\sigma/20)+1}\right] - 20 \log G(\Theta,\phi) \quad \text{Equation 1}$$

where σ is the difference in decibels between the maxima and minima of the probed field variation and $G(\Theta,\phi)$ is the normalised gain function of the probe. Eq. (1) is plotted in Fig. 1, to indicate the level of confidence that may be placed on a given range up to an angle Θ_o if the gain of the probe at Θ_o is $G(\Theta_o,\phi)$.

This result may be used to assess precision criteria for the range over a limited angular span which might well be sufficient for the measurement of the main beam and several sidelobes of high gain antennas. This technique has been shown to be successful through comparisons with measurements in an unechoic chamber and found to be satisfactory not just technically but in terms of savings in test range investment.

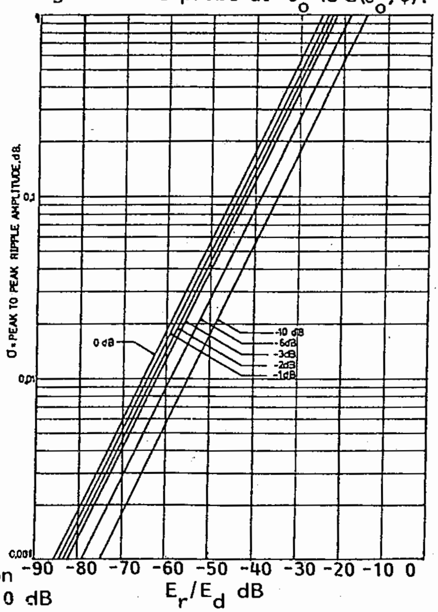

Fig. 1 σ vs E_r/E_d (dB) with probe in the plane of E_r and E_d. Worst case confidence level deterioration is shown for $G(\Theta_o)$ = 0 to -10 dB

RAPID NEAR-FIELD ANTENNA AND RCS MEASUREMENTS VIA PROBE ARRAYS

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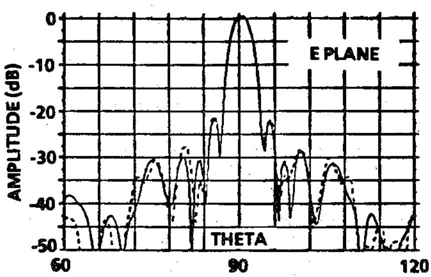
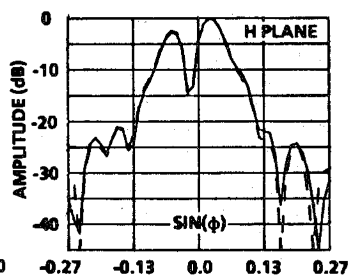
Gif-Sur-Yvette, France

This paper summarizes key results of cooperative research and development efforts to significantly reduce near-field measurement time by utilizing 1-dimensional or 2-dimensional arrays of electrically small probes in lieu of the single probe ordinarily used in conventional near-field measurement techniques. Results of numerical and experimental investigations show that the Modulated Scattering Technique (MST) employing arrays of hundreds of modulated scattering probes can be used to rapidly map the complex near-field of antennas or scatterers in a few seconds or minutes while maintaining good accuracy. The results also strongly indicate that classical receiving/transmitting arrays can be adapted for rapid near-field data collection and that MST or classical probe arrays can be used for rapid near-zone RCS data acquisition. Far-field patterns derived from MST and conventional near-field data, are displayed below for two reflector antennas (the monopulse reflector antenna was intentionally misaligned). MST and conventional near-field scanning times are indicated.





SUPELEC REFLECTOR ANTENNA
Diam. = 43.3 inches, Freq. = 6.0 GHz
MST (7 min) ——— Conventional (70 min) - - - -

GTRI MONOPULSE ANTENNA
Diam. = 48 inches, Freq. = 5.5 GHz
MST (3 min) ——— Conventional (75 min) — — —

† Now at U. of Missouri, Columbia, Missouri.
†† Now at U. Politécnica de Cataluña, Barcelona, Spain.

Tuesday AM

Joint AP-S, URSI-B Session 25

TRANSIENTS - ANALYSIS & MEASUREMENTS

Chairmen: D. Nyquist, Michigan State; S. Chaudhuri, Univ. of Illinois

Room: Sheraton Amphitheater *Time*: 8:25-11:00

TRAVELLING-WAVE ANTENNAS FOR TRANSIENT ILLUMINATION OF RADAR TARGETS

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The study of radar target discrimination using the E-pulse waveform synthesis scheme relies on the availability of suitable measurements of the transient scattered field responses of various targets. It is most important to maximize the duration of the late-time portion of the scattered field response, during which the target oscillates in its natural modes. This requires the ability to transmit a short duration pulse with minimal distortion in a free-space environment.

A travelling-wave antenna consisting of two wires formed into a "V" shape and terminated by appropriately chosen lumped impedances provides an adequate time domain antenna. A simple theory developed using retarded potentials and an assumed travelling-wave current distribution shows that the transmitted field waveshape maintains the narrow duration nature of a pulse present at its feed point. Similarly, a circular loop travelling-wave antenna also produces a transmitted waveform with the desired qualities.

Both types of antennas are tested inside a free-space transient measurement range consisting of an anechoic chamber and supporting test equipment. Experiments verify the viability of travelling-wave wire antennas for transmitting narrow duration pulse waveforms.

Diagnostic Backscattering Signature and Pattern Measurements of Triangle-Plate Dihedrals from 2 to 18 GHz and Comparison to Theory

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The triangle plate dihedral has several attractive features for use as a calibration target. It has a broad pattern in one principal plane and a narrow pattern in the other. In both patterns, the triangle plate shape produces lower sidelobes than a comparable square-plate dihedral. When oriented correctly, it can produce a strong cross-polarized backscattered echo for both linear and circular polarization with no same-sense return.

It has been shown that physical optics correctly predicts the performance of this target when its size is large in wavelengths. This paper shows signatures and patterns for smaller dihedrals in the resonant frequency region, where the joint dimension (d) is in the range $3 < kd < 100$. Measured data are presented and compared to physical optics and GTD calculations. Scattering mechanisms in addition to the corner bounce are identified and quantized.

SHORT PULSE SCATTERING FROM HUMAN TARGETS

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Sarasota, FLorida 33577

The application of short pulse techniques in the development of an optimum short range area sensor for detecting human intruders requires knowledge of the backscattered signals. This paper briefly describes the Anro Baseband Radar (ABR) as used for intrusion detection, discusses the human being as a radar target and presents the results of a measurement program to obtain backscattered signals from humans in the act of intrusion. The experimental results, in the form of time varying sampling scope waveforms, have been recorded on video tape and will be presented at the meeting.

The ABR system is fundamentally different than conventional radars. The ABR transmitted waveform is the transient that is generated by discharging a previously charged antenna structure. The waveform reflected from a target is received by a similar but separate antenna and the system waveform is a pulse modulated oscillation. The oscillation frequency is determined by the size and shape of the antenna. The BAR used in these experiments employed a 3.2 inch long dipole backed by a corner reflector. The pulse envelope is very closely approximated by a half cycle of a sinewave with a 6 nanosecond duration and an oscillation frequency of 1.54 GHz. The returned field was received by a similar antenna with the port voltage amplified by 28 DB in a broadband amplifier. The amplifier output was processed and displayed with a Tektronix 7854 oscilloscope using an S-4 sampling head.

Signals reflected from human beings (and other animals) can be expressed by the superposition of returns that originate at isolated scattering centers on the body. The situation is further complicated because the target is imaged by the ground. The human target is not a rigid body; therefore the scattering center positions vary relative to each other and to their images as the target moves. At a wavelength of 20 cm., a relative range change of 2.5 cm. between scattering centers can cause the instantaneous signal voltage to vary between a peak and a null. This phenomena causes returns from human beings (and other animals) to fluctuate even under relatively stable conditions . As objects move through the field established by an ABR system, fluctuating waveforms are produced. These waveforms contain unique information about the shape and motion constraints of the object in the field.

EXTRACTION OF NATURAL FREQUENCIES OF A RECTANGULAR PLATE FROM MEASURED RESPONSES

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The transient behaviors and natural resonances of metallic objects with various geometries have been studied with the SEM method by many workers in the last two decades. However, the case of a rectangular plate has not received much attention, with the exception of Pearson's approximate theoretical work.

In this study, the induced surface current on the plate is analyzed from two coupled surface integral equations. With this formulation a better convergence is achieved in the root determination. The MOM is used to find the natural modes of the plate, taking into account of the structure symmetry and numerical efficiency. The pole trajectory is studied in terms of the width to length ratio of the plate.

An experiment was conducted to measure the transient responses of rectangular plates illuminated by Gaussian pulses. From the measured responses, the natural frequencies of the plates were extracted with new methods developed by our group. Experimental results on the natural frequencies of the plates are compared with the theoretically predicted values.

A NUMERICAL TECHNIQUE FOR MODELING MOVING OBJECTS IN ONE AND TWO DIMENSIONS

Fady Harfoush* and Allen Taflove

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Gregory A. Kriegsmann

Department of Engineering Sciences and Applied Mathematics
Northwestern University, Evanston, IL 60201

New techniques for numerically modeling moving surfaces in one and two dimensions are presented here. The central idea is to define means by which the relativistic boundary condition across a moving surface S,

$$\hat{u}_n \times (\vec{E}_2 - \vec{E}_1) - (\hat{u}_n \cdot \vec{v})(\vec{B}_2 - \vec{B}_1) = 0.$$

can be implemented in a finite-difference time-domain (FD-TD) code. The methods presented here eliminates the need for a system transformation in which grid sizes are either compressed or stretched. Instead, our method gives a solution to the problem directly in the observer system of reference. This enables us to watch the time evolution of the wave as it strikes a moving surface, giving both near field and far field behavior. It also enable us to consider different types of motions, uniformly moving or accelerating objects, where exact analytical solutions do not exist in most cases. In this paper, we will only consider perfectly conducting surfaces. Two techniques are discussed which have shown to give excellent results when compared to analytical results. The first technique, presented last year for one dimensional problems, has been extended to two dimensions. This method relates the total tangential E field at the moving surface boundary to the total tangential incident E field in an FD-TD grid. For oblique incidence in a two dimensions domain, the wave is reflected at an angle given by the special theory of relativity. Together with this information we are able to reproduce published analytical results.

In order to further relax the condition imposed on our previous method that relates the tangential fields at the moving surface boundary, we developed a new method based on a derivative of the relativistic boundary condition. The newly derived form of equations are easily implemented in an FD-TD code and fits very well within the structure of the code. This method eliminates the need for a surface impedance to relate the tangential field components, and is purely based on the relativistic boundary condition. Again, a good agreement with published results is demonstrated.

A METHOD FOR SINGULARITIES EXTRACTION FROM SERIOUS NOISE BACKGROUND

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In our discussions, retaining the real-time virtue of Prony's method, utilizing the correlation technique and symmetric transform, the signal to noise ratio (SNR) threshold for singularities extraction is reduced from 36 dB to 6 dB (M=6). And in the case of Gauss noise, the anti-noise ability of the method is analized theoretically. The SNR definition of transient signal is also discussed, and a reasonable definition is proposed.

I. Let sample sequence be

$$f(n)=s(n)+x(n) \qquad n=0,N-1$$

where $s(n)=\sum_{i=0}^{M-1} A_i Z_i^n$ is a signal sequence, $x(n)$ is a noise sequence. Define a correlation sequence $r(k)=\sum_{n=0}^{N-k-1} f(n)\cdot f(n+k)$, then $r(k)=r_{ss}(k)+r_{xx}(k)+2r_{sx}(k)$.

where the first term is the signal, following two are noise. According to the concerned properties of noise, after correlating the most part of noise are concentrated at the first several points. Therefore, if the first some points are discarded, the noise influence will be considerably reduced. By this way, the SNR gain of the i th natural mode is

$$G_i = snr_i / (2N\sigma_i \rho^2 (1+2snr))$$

and $r(k)$ is turned into $R(k)$. Make a transform $y(k)=R(k)+R(4M-k)$, the Prony's method can be used to solve the singularities.

II. Up to now, there is no rational SNR definition for transient signal. We proposed

$$SNR=\sum_{n=0}^{N-1} S^2(n)/(V_n^2 N)$$

and N is limited by

$$\sum_{n=0}^{N-1} S^2(n)=0.99\sum_{n=0}^{\infty} S^2(n)$$

where V_n^2 is the average power of noise.

Notes

Tuesday AM

Joint AP-S, URSI-B Session 27

NUMERICAL METHODS: TIME-DOMAIN FINITE DIFFERENCE

Chairmen: D. R. Pflug, Atlantic Research; Y. C. Cho, NASA

Room: Sheraton Regency B *Time*: 8:25-12:00

8:30	**A Super-Absorbing Boundary Algorithm for Solving Electromagnetic Problems by Time-Domain Finite-Difference Method** J. Fang, K. K. Mei, University of California, Berkeley	See AP-S Dig.
8:50	**New General Grid Finite-Difference Time-Domain Methods for Maxwell's Equations in Two Dimensions** S. L. Ray, Lawrence Livermore National Laboratory	126
9:10	**A Posteriori Correction of Reflections from Mesh Boundaries for Exterior Wave-Equation Problems** E. K. Miller, W. D. Murphy, Rockwell International Science Center	127
9:30	**The Application of The On-Surface Radiation Condition to Pulse Scattering of Two-Dimensional Electromagnetic Waves** T. G. Moore, A. Taflove, G. Kriegsmann, Northwestern Univ.	128
9:50	**A One-Dimensional Demonstration of the Finite Difference Time Domain Technique Using a Personal Computer** R. Luebbers, The Pennsylvania State Univ.	See AP-S Dig.
10:10	**COFFEE BREAK**	
10:40	**Scattering from Thin Dielectric Plates Using the Finite-Difference Time-Domain Technique** K. R. Demarest, J. Huang, D. Long, University of Kansas	129
11:00	**Use of Electromagnetic Wave Absorbers at FD-TD Grid Boundaries as an Improved Radiation Boundary Condition** M. Strickel, A. Taflove, Northwestern Univ.	130
11:20	**Adaptive Radiation Boundary Conditions** J. G. Blaschak, A. Taflove, G. A. Kriegsmann, Northwestern Univ.	131
11:40	**Variable-Mesh Time-Domain Finite-Element Method for the Analysis of Microstrip Structures** A. Cangellaris, University of Arizona	132

NEW GENERAL GRID FINITE-DIFFERENCE TIME-DOMAIN METHODS FOR MAXWELL'S EQUATIONS IN TWO DIMENSIONS

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Time-domain electromagnetics problems have generally been solved using the finite-difference, time-domain method developed by Yee (*IEEE Trans. Antennas Propagat.*, **AP-14**(3), 302–307, 1966). This method, although accurate, efficient, and powerful, is limited to use on regular orthogonal grids. To overcome this limitation and obtain accurate solutions to more complex problems, research in recent years has focused on general, boundary conforming methods based on either finite difference or finite element techniques.

In this paper we discuss a new general grid method for solving two dimensional, time dependent, electromagnetics problems. The method is based on spatial finite-difference approximations to both the integral and differential forms of Maxwell's curl equations (Ampere's and Faraday's Law) combined with leap-frog time integration.

To illustrate the method, consider a problem described by a 2-D mesh in the $x-y$ plane with TE_z field polarization. Unknowns describing the magnetic field, H_z, are associated with cell centers while electric field vectors are located at and oriented along cell sides. An approximation to the line integral of the electric field around a cell can then be readily computed, which in turn drives the time derivative of the magnetic field directed through the cell via Faraday's law. The side-based electric fields are obtained from the differential form of Ampere's law using a six point spatial difference stencil. The use of this six point approximation distinguishes this method from previous general grid finite-difference techniques which rely on less accurate two point approximations. The six point stencil is derived using simple ideas of coordinate transformations and polynomial interpolants and is designed to reduce to a simple two point difference when the method is used on a regular grid.

Several features make this method attractive. First, it is more accurate than previous general grid finite difference and finite element methods. Second, unlike earlier finite element based methods, it reduces to the standard finite-difference scheme when applied on a regular orthogonal grid. Third, although the method was developed for quadrilateral based meshes, it can be extended to triangle based meshes and to grids with mixtures of quadrilateral and triangular elements. Finally, the method is simple and efficient.

The method is illustrated by studying wave propagation through a variety of skewed meshes. The effects of dispersion and wavefront distortion are examined and compared to other methods.

A POSTERIORI CORRECTION OF REFLECTIONS FROM MESH BOUNDARIES FOR EXTERIOR WAVE-EQUATION PROBLEMS

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Numerical modeling of electromagnetic radiation and scattering problems has predominantly involved integral-equation (IE) formulations even though a differential-equation (DE) approach which uses the Maxwell curl equations provides a more general basis for model development. There are various reasons for this concentration of attention on IE approaches, perhaps most important being the challenge in exterior problems of truncating the spatial solution mesh needed for the DE model. Whereas for homogeneous-media problems the IE need sample for induced sources only over bounding surfaces, a DE model must sample the fields throughout the solution volume. This means that for exterior problems, the DE solution mesh could in principle extend to infinity, a computationally impracticable situation which in practice is circumvented by terminating or closing the mesh as close to the problem volume as possible at the so-called "radiation boundary".

Mesh closure requires use of some auxilliary constraint beyond that which comes from the wave equation itself, the choice of which is the subject of this paper. We briefly discuss both "local" and "global" lookback closure conditions with the goal of comparing various alternatives with respect to their computational cost and accuracy. An alternative procedure for eliminating closure-boundary reflections is described. It involves decomposing the azimuthal Fourier components of the scattered field on two concentric circular surfaces enclosing the solution mesh into outward and inward propagating Hankel waves. The inward component, caused by inadequately satisfying the radiation condition at the closure boundary, may be regarded as a contaminating addition to the prescribed excitation field at the surface of the object being modeled. The problem of zeroing the closure-boundary reflections then becomes one of *a posteriori* deconvolving the effect of this unwanted field from the desired exciting field for which at least two approaches can be identified. A simpler but less accurate approach is to compute the scattered field using only the outward-propagating Hankel waves. A more accurate approach is to correct the computed fields so that those which would have been caused by only the desired excitation are recovered. Implementation of the latter approach is complicated by the mode coupling that can occur for all but the simplest problems. Representative results will be presented to demonstrate the properties of this deconvolution approach. The relative validity of the various methods investigated is compared with respect to the surface-, near- and far-field behavior.

THE APPLICATION OF THE ON-SURFACE RADIATION CONDITION TO PULSE SCATTERING OF TWO-DIMENSIONAL ELECTROMAGNETIC WAVES

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The on-surface radiation condition method (OSRC) has been used by a variety of authors to solve time harmonic problems. This method provides a great reduction in computational work in comparison to numerical methods which require the solution of the full Helmholtz equation. The OSRC method also produces better approximations for the induced surface currents in comparison with high frequency techniques and is also much simpler to apply. The OSRC method achieves the simplification of the problem by applying a second order mode annihilating boundary operator on the surface of the target.

This paper extends the OSRC method to time-domain pulses scattering problems. The boundary operator is formulated directly in the time domain and then applied to the surface of the target. For an incident TM-polarized plane wave an algebraic expression for the surface currents is determined directly. In contrast, for a TE polarized plane wave a partial differential equation is produced which is solved using a short time asymptotic expansion. The cases of scattering from a circle and and ellipse will be examined.

SCATTERING FROM THIN DIELECTRIC PLATES USING THE FINITE-DIFFERENCE TIME-DOMAIN TECHNIQUE

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The Finite-Difference Time-Domain (FDTD) technique has proven to be a very useful tool in the calculation of the scattering characteristics of a broad class of scatterers. Geometries that are routinely modeled by this technique include both perfectly conducting and dielectric structures. Although the method of calculation is in the time domain, both transient and steady state results can be obtained. Even for frequency domain results, the FDTD technique has some distinct advantages over more typical method of moments (MOM) techniques, particularly in the case of dielectric scatterers.

A scattering geometry of considerable current interest is that of thin dielectric sheets, possibly with conductor backing on one side. The reason for the importance of this geometry is the current and increasing use of dielectric materials in aircraft and missile designs. Due to the thinness of these sheets, this class of geometries constitutes a challenge to FDTD modeling, as it would be quite inefficient to use a spatial grid that was small enough to actually resolve the dielectric.

We present a method of modeling dielectric sheets, with or without conductor backing, in FDTD codes in such a way that the spatial cell size is not constrained to be on the order of the dielectric thickness, thus saving both computer time and storage requirements. This augmentation involves changing the usual (free space) relationship between E and H in those cells that contain the thin dielectric. By making those cells "smart," the entire calculation is not burdened by the need for the very large number of cells that would be necessary if the "brute force" method were used.

Example transient calculations will be shown comparing results of this technique for the case of plane wave excitation with those obtained from the simple cannonical frequency domain scattering from an infinite layered media.

USE OF ELECTROMAGNETIC WAVE ABSORBERS AT FD-TD GRID BOUNDARIES AS AN IMPROVED RADIATION BOUNDARY CONDITION

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The finite-difference time-domain (FD-TD) method is a direct solution of Maxwell's time dependent curl equations using a fully explicit numerical algorithm to simulate real-time wave propagation and scattering. Field boundary conditions at adjacent dissimilar media are automatically satisfied by the curl-equations analog. However, the radiation condition is not inherent and must be formulated separately to properly work in the near field and in the time domain.

The radiation condition must absorb outgoing scattered fields incident on the grid boundary from a variety of angles with as little reflection as possible. The majority of radiation boundary conditions in use today are of an analytical nature, wherein electric fields adjacent to, and interior to the grid boundary are used to obtain an estimate for the electric fields on the boundary itself.

This report will describe a radiation boundary condition that uses electric and magnetic losses to absorb the outgoing scattered waves. The absorber consists of a perfect conductor, which surrounds the target, and is coated on the inside with a layered absorbing material.

The absorber is synthesized using a nonlinear optimization routine which adjusts the permittivity, permeability, and electric and magnetic conductivity of each layer of the absorber to reduce to the smallest extend possible, the unwanted reflections that occur when the absorber is illuminated by an outgoing wave. This report will show that an absorber synthesized in this manner, that is only 5 FD-TD cells thick, provides better performance than the commonly used Mur analytic radiation boundary condition.

In addition, the lossy absorber is advantageous in that the absorber exists within the FD-TD code as part of the coefficients that multiply the electric and magnetic fields during the time stepping process. Consequently no additional programming is required to implement the absorber except to initially assign the correct electric and magnetic parameters to the FD-TD cells that make up the absorber.

ADAPTIVE RADIATION BOUNDARY CONDITIONS

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The current practice in finite-difference time-domain (FD-TD) simulations of electromagnetic wave scattering utilizes an approximate second-order one-way wave equation to determine the field values, at each time step, for points on the boundary, $\partial\Omega$, of a computational domain. The boundary condition is derived using Padé approximation of the pseudo-differential operator representing an exact, but non-local, absorbing boundary condition. The Padé boundary condition is applied *everywhere* on $\partial\Omega$ (except at the corners of a Cartesian domain, which require special handling) and has good absorption properties for scattered waves striking the boundary close to normal incidence. This approach has produced good results in practice, but does not address the possibility of scattered waves striking $\partial\Omega$ over a wide range of angles significantly distant from normal incidence. In this situation, the performance of the Padé boundary condition is is known to degrade.

This paper presents an algorithm which produces a radiation boundary condition that is optimized for waves striking the computational boundary. Because the nature and direction of waves scattered from an arbitrary target can not be known with certainty prior to the start of a simulation, the algorithm adapts the boundary condition to the particular target under consideration. The theory enabling the design of boundary conditions having optimum absorption for waves at arbitrary angles of incidence is well-established. Prior work has shown that the coefficients of the boundary condition determine this characteristic of its performance. In the present work, the coefficients of the boundary condition are viewed as adjustable parameters in a model for the boundary operator. Standard techniques from parameter estimation theory are applied to determine the optimum choice of boundary condition coefficients for each point on $\partial\Omega$ at each time step of the simulation. Results of numerical experiments are presented which demonstrate the effectiveness of the adaptive boundary condition algorithm in actual scattering calculations.

VARIABLE-MESH TIME-DOMAIN FINITE-ELEMENT METHOD FOR THE ANALYSIS OF MICROSTRIP STRUCTURES

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Time-domain finite difference (TDFD) and finite element (TDFE) methods have been with us for quite some time and have found extensive application in the analysis of transient electromagnetic wave scattering and radiation. It is only recently, however, that investigators have been considering these time-domain techniques as perspective tools in the analysis of microstrip structures. It is interesting to note that the first attempts in this direction were characterized by the use of sinusoidal excitations, which compromises the inherent advantage of the time-domain method of producing wideband frequency domain results with a single impuslive excitation. Recent work in this area (K. K. Mei, U. C. Berkeley, *private comm.*) has demonstrated the feasibility of the TDFD in producing frequency domain design data for microstrip structures through Fourier transformation of transient data.

In an attempt to improve the computational efficiency of TDFD and TDFE methods the use of different size grids in the discretization of volumes with different dielectric properties (substrate with $\epsilon_r \sim$3-13 and air) is being investigated in this paper. In addition to considerably reducing the number of unknowns, the use of a variable mesh is shown to reduce the loss of accuracy caused by the numerical dispersion. This stems from the fact that the Courant limit requires the mesh size Δh to be chosen such that $c\Delta t < \Delta h/\sqrt{3}$ for TDFD or $c\Delta t < \Delta h$ for TDFE, and it is well known that numerical dispersion increases as the Courant number reduces to values much less than 1. Notice then that for a uniform mesh with Δh chosen as above, the Courant number for the substrate with velocity of propagation $v_s = c/\sqrt{\epsilon_r}$ becomes much less than 1 as ϵ_r increases, which in turn results in higher numerical dispersion for the wave propagating in the substrate. This can be avoided by choosing the grid size in air larger than that used in the substrate.

Several issues related to the implementation of nonuniform grids in the numerical solution of the hyperbolic system of Maxwell's equations are discussed. Among them are, the way of handling nodes at the interface between media with different dielectric properties and different size grids, and the importance of the adequate sampling of the wave in the coarser grid. The latter is of major importance and is due to the fact that any wave which is poorly represented in a coarser grid will change numerical phase velocity when passing into a finer grid. Various computed results are presented that confirm our findings.

Tuesday AM

URSI-F Session 29

MULTIPATH AND FADING

Chairmen: A. R. Webster, University of Western Ontario;
L. Tsang, University of Washington

Room: Sheraton Comstock A *Time*: 8:25-12:00

ANGLE-OF-ARRIVAL MEASUREMENTS RELATED TO TERRESTRIAL MICROWAVE COMMUNICATIONS SYSTEMS

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Some recent results are presented from the operation of a system designed to measure accurately the amplitude and angle-of-arrival in the vertical plane of each of the individual rays in a multipath situation on typical microwave communications links. Based on a 16-element wide aperture (667λ) array, the system is capable in principle of a resolution approaching 0.1° and of repeating the measurements at rates up to 20 s^{-1}; the results presented use a repetition rate of 1 s^{-1}. Each complete measurement contains the complex amplitude at each of the 16 elements and these are stored for further processing; this includes Fourier transforming the weighted element amplitudes to give a direct measure of the ray amplitude and angle-of-arrival (see Webster and Scott, Trans. IEEE Ant.Propagat., AP-35, 1, 94-99).

The analysis is an ongoing process and much information is contained in the accumulated data. At the present time, the effort is aimed at the following:

(a) **Angle-of-Arrival distribution.** This includes the distributions of individual rays and in the separation of the strongest rays. Preliminary estimates show separations of around 0.2° are common between the strongest rays, while angles over a total range of about 0.7° or greater are observed.

(b) **Amplitude distribution.** The amplitudes of individual multipath rays are of some importance in assessing the impact on systems. Both enhanced and depressed (relative to the normal) ray amplitudes are observed with changes occuring typically in the order of a few seconds. Strong "elevated" and "direct" rays appear to be about equally likely.

(c) **Diversity considerations.** Simulation of both space and, more importantly, angle diversity systems are underway and planned using the collected data, and it is expected that useful information will emerge here.

STATISTICAL PROPAGATION MODELING OF SIGNAL FADING ON LAND MOBILE SATELLITE SYSTEMS

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A simple empirical model for predicting primary fade statistics for a vegetatively shadowed land mobile satellite signal is presented. Predicted fade statistics using propagation parameters based on the analysis of experimental data are presented. Also presented are results of using the propagation parameters from the empirical model to drive a propagation simulator to produce the secondary statistics, average fade duration and level crossing rate.

THEORETICAL PREDICTION OF UHF VARIABILITY IN URBAN ENVIRONMENTS

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Measurements made in the UHF band for systems such as cellular mobile radio have found that the signal received by an antenna at street level undergoes rapid variations as the antenna is moved over a distance of above one-half wavelength. When the received signal is averaged over a distance of 10-20 wavelengths, the result is referred to as the sector average. Measurements in urban environments have typically found that for sectors at a given distance from an elevated fixed antenna, the sector averages vary randomly with approximately lognormal distribution. Finally, the mean of the distribution varies with distance from the fixed antenna. A theoretical propagation model describing how building in the urban environment influence the distance dependence of the mean was previously developed at the Polytechnic.

In work reported here, we show how the propagation model can be extended to predict the statistical properties of small sector averages. The model is based on the recognition that away from the high rise urban core, buildings are organized in rows by the street system, with narrow or no gaps on either side of the buildings, and the buildings are of fairly uniform height. Propagation is therefore a process of multiple forward diffraction past rows of buildings. Variations in the small sector average signal arise from two sources. One is the random variation of building heights in rows prior to the mobile. The second is due to variations in building construction, gaps between buildings, and foliage in the rows on either side of the mobile. The two sources of variation are sequential in nature, so that the resulting variation in signal are additive in dB, leading to lognormal statistics. Results of numerical simulation studies are presented showing how the two sources of variation generated the statistical distribution of the sector average signal.

GTD PREDICTIONS OF TERRAIN EFFECTS ON WIDEBAND CHANNEL DELAY, COHERENCE BANDWIDTH, AND RECEIVED SIGNAL LEVEL FOR A DIFFRACTION PATH

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A propagation model for prediction of radio path loss for line-of-sight (LOS) and near-LOS paths for frequencies from approximately 100 MHz to 10 GHz has been under development for several years. This model approximates the terrain as a two-dimensional profile, then computes the received signal as a combination of direct, reflected, and diffracted rays using GTD wedge diffraction.

Recent efforts have been directed at extending the GTD model to wideband signals, with application to tactical spread spectrum communication systems. This involves simulating the spread spectrum channel and converting the GTD results to the time domain. Results for a short path (120 meters) which involved only direct and reflected rays have been presented previously (R. J. Luebbers, 1987 URSI Meeting, Blacksburg, VA). These results included time delay, delay spread, and absolute wideband path loss (wideband received signal level), with comparisons between GTD predictions and measurements made by SRI International showing good agreement.

More recently, wideband measurements for an 8 km path involving diffraction and reflection (below LOS) have been made by SRI International. GTD predictions of time delay, delay spread, and absolute wideband path loss are compared with measured values and reasonable agreement is obtained. In addition, the GTD model has been extended to predict the channel coherence bandwidth, and comparisons with measured values for both LOS and below-LOS paths have been made.

EFFECTS OF ATMOSPHERIC HORIZONTAL INHOMOGENEITIES ON THE BEHAVIOR OF MICROWAVE LOS LINKS

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The vast majority of the radio propagation studies of deep, selective fadings in the received signals of line-of-sight microwave links has been performed by combining a horizontally stratified atmosphere with ray-tracing techniques. These are static models, which generally only detect the existence of a median, quasi-flat depression in the received signal (a commonly accepted pre-condition for the occurrence of more severe fadings). That is, these models, although correctly indicating potentially damaging situations, more realistically represent average conditions. One can convincingly argue that considerable variations about these conditions may be present. Indeed, measurements of both horizontal atmospheric inhomogeneities and time variations of vertical refractive-index structures are available in the literature. It has also been shown how these departures from average conditions in the atmosphere are translated into an analogous behavior in the bending of the direct ray.

To simulate a dynamical situation, a horizontally stratified atmosphere leading to median defocussing of the direct ray or to multipath conditions in a particular microwave line-of-sight link will be preliminarily characterized. It will then be assumed that the parameters defining this medium slowly vary about their pre-established average values. As an alternative model, it will be assumed that, in addition to the former "background" atmosphere, two-dimensional "frozen-in" inhomogeneities, leading to horizontal variations in the refractive index, drift along the radio link.

A suitable ray-tracing program (which also accounts for earth's sphericity) will then be repeatedly used to calculate variations in the important parameters of the radio link (angles of launch and arrival of the rays reaching the receiver, their relative amplitudes and time delays, as well as the intensity of the received signal) when the above structures change and/or drift as described. The effects of two fading mechanisms on the received signal will be analyzed and compared. In the first mechanism, an interference pattern results from a combination of a defocussed direct ray with another reflected on a rough ground. In the second, analogous results are obtained from purely atmospheric rays.

Gaussian Beams for Transmission of a High Frequency Aperture Diffracted Field Through a Nearby Cylindrically Curved Dielectric Layer

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and

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Abstract

Ray-optical methods for tracking high frequency fields through a complex environment cannot easily be implemented when the ray transition region surrounding a caustic, shadow boundary, etc., generated at a first encounter with the propagation environment interacts with another environmental obstruction. The difficulties can be avoided when the field tracking is carried out by Gaussian beams because these wave objects, which propagate along complex rays,do not fail in real-ray transition zones. The conglomerate of beams is established by representing an initial aperture field rigorously as a discretized superposition of Gaussians on a configuration-wavenumber lattice. The beam method is applied here to determining the field transmitted through a wide slit in a plane boundary with a nearby cylindrically curved dielectric layer when the incident field is a plane wave. Emphasis is on tracking the aperture-edge produced shadow boundary transitions through the layer, which is situated well within the Fresnel zone of the aperture but in the far zone of the beam elements. Multiple reflections inside the layer are accounted for but those between the layer and the aperture plane are ignored. These phenomena can be well modeled by a Kirchoff approximated aperture field. Numerical results for different beam parameters are shown to generate the same overall field behavior, thereby demonstrating the internal consistency of the beam summation. Successive addition of individual beam contributions demonstrates how the field builds up to its final value.

HORIZONTAL GRADIENTS OF THE REFRACTIVE INDEX AND MULTIPATH PROPAGATION

Valérie Ciarletti (CNET/PAB/RPE, France)

The PACEM3 experiment was aimed at a better understanding of the physical situations and mechanisms that can involve multipath propagation on line of sight links. The results of a previous experiment had pointed out the likely importance of horizontal gradients of the refractivity N. In that experiment, we investigated both the horizontal and vertical gradients of N in the lowest part of the troposphere.

The experiment consisted of a 50 km-long microwave link equipped with a microwave link analyser (MLA) giving the atmospheric transfer function from 10.7 to 11.7 GHz. An instrumented tethered balloon placed in the vicinity of the link gave the vertical profile of N from ground to about 300 meters; the horizontal gradients were measured by sensors installed on board an aircraft flying along the radio-link.The data were collected during clear nights of June 1986 in the south-west of France.

In this paper, after a description of the experiment, we present some results from the aircraft data analysis. During two nights when radio data demonstrated the existence of multipath propagation, the meteorological situations were observed to be different but involving in both cases important refractivity horizontal gradients.

The first night showed the combined effects of the wind circulation and the orography. A strong correlation between the vertical component of the wind and the value of N was observed. We locally found a 15 units increase of the N value over about 10 km. Superposed to this structure there were gravity waves with a wavelength of about 300 meters and amplitude of about 5 N-units.

During the second night, we observed the incoming of a wet bulk that at first partially , then totally affected the link, inducing at the transition a difference of 15-20 N-units over about 5km.

The possible effects of these various features on a radio link have been simulated by ray-tracing. These results bring out the importance of horizontal gradients in multipath situations and the necessity to take them into account when studying radio propagation.

DISPERSIVE MICROWAVE FADING AND LOWER ATMOSPHERIC STRUCTURE: AN OBSERVATIONAL STUDY

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Simultaneous measurements of microwave fading and lower atmospheric conditions were carried out in Georgia beginning in 1986 as a part of the continuing efforts to studying the line-of-sight digital radio performance. The goal is to gain a fundamental understanding of the atmospheric mechanism that causes dispersive fading, which, in turn, may provide clues in modeling dispersion occurrence from a climatological perspective. This presentation focuses on findings pertinent to the primary objective.

Microwave fading was measured in the 6-GHz band and information on dispersive fading was obtained from a pair of sinusoidal radio signals separated by 19.8 MHz. A monostatic Doppler sodar and a meteorological tower at midpath monitored the lower atmospheric structure. The acoustic sounding provides information on three-dimensional mean wind velocity as well as turbulent characteristics of the nocturnal boundary layer. Tower measurements give the variation of vertical refractivity gradients up to the antenna levels as well as detailed weather conditions at the site.

Results suggest that dispersive multipath fading is caused by the combination of quasi-steady-state low-level temperature inversion under the existence of subsidence inversion. This low-level inversion is often found to be a ground based radiation inversion. Subsidence tends to limit the growth of the radiation inversion layer. When the balancing height is 100 to 150 meters measured at midpath, fading is active and dispersive for a 35-mile path with both transmitting and receiving antennae at 60 meters above grade. Under this condition, the depression of the mean received power level is primarily dictated by the origin of the air mass.

The downward transport of momentum flux (in the form of dry eddies of all sizes) under a synoptic high pressure system is the principal mechanism of forming a superrefractive environment. It is assumed that these dry eddies from higher altitudes that form local refractivity-gradient anomalies in various length scales are the cause of dispersiveness. This postulation will be substantiated by case studies of some observed significant episodes of dispersive fading.

STATISTICS OF MULTIPATH CHANNEL TWO-RAY MODEL PARAMETERS MEASURED AT 4 AND 6 GHZ IN BRAZIL

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Statistics of multipath channel two-ray model parameters, namely the multipath fading ocurrence factor, the maximum fading depth and the multipath delay, are presented. The results have been obtained from one year mesurements of continuity pilot level and AGC voltage in four line-of-sight analog microwave links, using the Taylor and Shafi method (IEEE Trans.Com.-31,pp.1103-1109). Although this method has the limitation of not allowing the separation between minimum phase and non-minimum phase fadings, it has been chosen due to its simplicity, as the present experiment is part of an extensive measurements program that intends to cover several regions in Brazil.

Three of the links where the measurements were made operate at 6 GHz,with path lengths of 40, 44 and 57 km. The fourth link operates at 4 GHz, sharing the same propagation path with the 6 GHz/57 km link. All links have a common end.

The ratio of multipath ocurrence factors measured at each frequency in the 57 km link are proportinal to the frequency ratio to the power 1.5.

The histograms of multipath delay obtained for all four paths are well aproximated by exponential density functions, with mean delays equal to 0.74, 1.69, 0.57 and 0.51 nsecs, respectively.

The statistical behavior of maximum fading depth could not be completely established with the data available at the moment. The measurements will be carried on for a longer period, in order to clarify this point.

Tuesday AM

Joint AP-S, URSI-B Session 31

WAVEGUIDES

Chairmen: A. Oliner, Polytechnic University;
J. A. Malherbe, University of Pretoria

Room: Schine 304A *Time*: 8:25-12:00

8:30	**Periodically Loaded Dielectric Waveguides** K. A. Zaki, S. Chen, University of Maryland	See AP-S Dig.
8:50	**Application of Field Theory Analysis of Multiport-Multidiscontinuity Structures to Circular-Electric Mode Waveguide Junctions and Couplers** J. M. Rebollar, J. Esteban, E.T.S.I.	See AP-S Dig.
9:10	**Dyadic Green's Functions for Inhomogeneousely Filled Waveguides** A. S. Omar, K. Schunemann, Technische Universitat Hamburg-Harburg	See AP-S Dig.
9:30	**Discontinuities of Dielectric Loaded Waveguides** S. Chen, C. Chen, K. A. Zaki, University of Maryland	See AP-S Dig.
9:50	**Propagation Characteristics Of A Corrugated Dielectric Lined Circular Waveguide Feed** P. McCormack, T. C. Rao, University of Lowell	See AP-S Dig.
10:10	**COFFEE BREAK**	
10:40	**A Mode-Transforming Polarization-Rotatable Launcher for the ATF Fusion Experiment** T. S. Bigelow, T. L. White, H. D. Kimrey, C. R. Schaich, Oak Ridge National Laboratory	See AP-S Dig.
11:00	**Analysis of Discontinuities in Dielectric Slab Waveguides** S. Chung, C. Chen, National Taiwan University	See AP-S Dig.
11:20	**The Eigen-Weighted BIEM for Solving Arbitrary Cross-Section Waveguide** L. Zhu, W. Zhang, Nanjing Institute of Technology	See AP-S Dig.
11:40	**Mode Conversion Techniques for Magnetically Coated Hybrid Horns for Improved Radiation Performance** J. H. Wang, V. K. Tripp, Georgia Institute of Technology	144

Mode Conversion Techniques for Magnetically Coated Hybrid Horns for Improved Radiation Performance

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A circular waveguide horn with a highly lossy magnetic coating on its interior wall can support the HE_{11} hybrid mode as the corrugated horn if the waveguide diameter is large. [Lee, et. al., 1985 IEEE AP-S Symposium, Vancouver; also a pre-publication paper communicated to the authors]. However, this horn suffers from a large 10 dB loss in antenna gain.

In this study, analyses and experiments are carried out to investigate and characterize gain loss in magnetic horns. The large gain loss in the design of Lee, et al. is due to an inefficient H_{11}-to HE_{11} mode conversion mechanism, which leads to impedance mismatches and power dissipation of non-HE_{11} modes.

Two approaches to improve mode conversion are examined. One is to have a mode-converter section between the H_{11} waveguide and the magnetically coated HE_{11} horn based on the techniques of corrugated guide, dielectric loading, and conducting-stip loading. Analytical and experimental results on these techniques will be presented.

The other approach is to achieve low-loss mode conversion directly in the magnetic horn. The feasibility of this approach will be discussed.

Tuesday AM

URSI-B Session 33

EM THEORY II

Chairmen: J. Van Bladel, University of Ghent;
M. Catedra, Universidad Politecnica de Madrid
Room: Schine 304C *Time*: 8:25-12:00

A TECHNIQUE FOR SOLVING THE PROBLEM OF SCATTERING BY THICK PERIODIC STRUCTURES

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The problem of interest is scattering by a thick slab of structured material which is periodic in the plane of the slab faces, is uniform with respect to either the axis normal to the slab faces or an axis at an angle to the slab faces, and has lossy conduction paths that extend through the slab from face to face.

Straightforward application of the method of moments to the full slab thickness requires the use of a large number of unknowns to model the current distribution inside the slab. This is obviously undesirable, especially as the number of unknowns increases proportionately to the slab thickness.

This paper describes a simplified approach in which the solution for the thick slab is developed from the solution for a thin slab plus the determination of a small set of modes, those with the least attenuation, which are adequate to describe the field inside the structure sufficiently far away from a slab face. The effort required in this approach is essentially independent of the slab thickness.

Direct determination of the low attenuation modes has been carried out, but it is a tedious procedure because it involves solving a matrix eigenvalue problem in which the matrix elements are functions of the complex eigenvalue and thus must be recomputed at every step.

A more efficient approach is to solve a thin structure by the method of moments and then use Prony's method to extract the required modes.

Comparisons are presented here between method of moments applied to the thick structure and the two variations of the simplified approach.

SOLUTIONS OF MAXWELL'S EQUATIONS BY MATRIX FORMULATION

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The usual approach in solving Maxwell's equations in time harmonic form

$$\nabla \times \vec{E} = -j\omega\mu\vec{H} \qquad \nabla \times \vec{H} = j\omega\epsilon\vec{E} + \vec{J}$$

is by means of vector differential operations upon the vector potential function derived from the given current distribution $\vec{J}$. By employing the free-space Dyadic Green's function, we may bypass the vector potential function, and thereby establish a direct relation between the current source $\vec{J}$ and the resulting fields $\vec{E}$ and $\vec{H}$:

$$\begin{cases} \vec{E}(\vec{r}) = -jk\eta \displaystyle\int_V \left(1 + \frac{1}{k^2}\nabla\nabla\cdot \right) g(|\vec{r} - \vec{r}'|)\, \vec{J}(\vec{r}')\, dv' \\ \vec{H}(\vec{r}) = -jk \displaystyle\int_V \frac{1}{-jk} \nabla \times\ g(|\vec{r} - \vec{r}'|)\, \vec{J}(\vec{r}')\, dv' \end{cases}$$

where $\eta = \sqrt{\mu/\epsilon}$ and $g(r) = e^{-jkr}/4\pi r$. Thses solutions are, however, quite involved in performing the numerical calculation, because of the vector differential operations in addition to the integration. By some mathematical manipulation, it can be shown that the complicated vector differential operations can be replaced by the simple vector algebraic operations. The results are

$$\begin{cases} \vec{E}(\vec{r}) = -jk\eta \displaystyle\int_V g(R) \left\{ \left(1 + \frac{1}{jkR} + \frac{1}{(jkR)^2} \right)(1 - \hat{R}\hat{R}\cdot) + \left(\frac{-2}{jkR} + \frac{-2}{(jkR)^2} \right) \hat{R}\hat{R}\cdot \right\} \vec{J}(\vec{r}')\, dv' \\ \vec{H}(\vec{r}) = -jk \displaystyle\int_V g(R) \left\{ \left(1 + \frac{1}{jkR} \right) \hat{R} \times \right\} \vec{J}(\vec{r}')\, dv' \end{cases}$$

where $R = |\vec{r} - \vec{r}'|$, $\hat{R} = (\vec{r} - \vec{r}')/R$. These are exact solutions, and are especially useful in numerical applications. They may also be written explicitly in matrix formulation so that the source and fields can be expressed in any desired coordinate systems.

If the electromagnetic fields, either in the near field (Fresnel region) or in the far field (Fraunhofer region), are of primary interest, the formulation can be greatly simplified. The fields are easily derived by simple matrix multiplication whenever the radiation vector is determined.

TRANSLATIONAL-ROTATIONAL ADDITION THEOREMS FOR SPHEROIDAL VECTOR WAVE FUNCTIONS

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In attempting solutions to electromagnetic scattering and radiation problems involving two (or more) bodies by means of multipole expansion techniques, it becomes necessary to transform the outgoing EM waves in the coordinate system of one body which scatters or radiates the waves into the incoming EM waves in the coordinate system of the second body which receives the waves by means of appropriate vector addition theorems. In the case of two prolate spheroids in parallel configuration (B.P. Sinha and R.H. MacPhie, IEEE Trans. AP, 31, 294-304, 1983; B.P. Sinha and R.H. MacPhie, IEEE Trans. AP, 33, 1255-1263, 1985), translational addition theorems for prolate spheroidal vector wave functions (B.P. Sinha and R.H. MacPhie, Quart. Appl. Math, 38, 143-158, 1980) are applied since the two coordinate systems are merely translated with respect to each other.

In the case of general configuration of two prolate spheroids (or oblate spheroids) the translational addition theorems for vector spheroidal wave functions must be extended to include the rotation of the coordinate systems relative to each other. This extension is considered in this paper and consequent development of translational-rotational addition theorems for spheroidal vector wave functions is presented.

THE GREEN'S FUNCTION OF A TORUS

R.K. Ritt, Department of Mathematics, Illinois State University

We revisit the scalar equation

$$\Delta G + k^2 G = - f,$$

exterior to a torus generated by a circle of radius b rotated with radius a about the z-axis. The region is described in terms of the toroidal coordinates (u,v,w) by:

$$x = ct \cos w \ ; \ y = ct \sin w \ ; \ z = c(\cosh u - \cos v)^{-1} \sin v.$$

In this, $t = (\cosh u - \cos v)^{-1} \sinh u$, $c2 = a^2 - b^2$, and $0 \leq u \leq u_o$, where $\cosh u_o = a/b$.

We assume that $ka \gg 1$ and $kb \ll 1$. Either G=0 or $G_u = 0$ when $u = u_o$.

When the source is sufficiently angularly separated from the z-axis, numerical investigations have indicated that there are significant features of the diffracted field not obtained by GTD (T.B.A. Senior and T.W.Burns, URSI Symposium. Budapest, 1986). Nor have we been able to obtain useful representations by means of the Weston wave functions.

Set $G = t^{-1/2} H$. The wave equation can then be written:

$$H_{uu} + H_{vv} + (\sinh u)^{-2} (H_{ww} + H/4) + k^2 c^2 (\cosh u - \cos v)^{-2} H = -t^{-1/2} J f/c = g.$$

where J is the Jacobian of the transformation above. Although this is not a separable problem, the periodic problem

$$Y_{vv} + k^2 c^2 (\cosh u - \cos v)^{-2} Y = -yY$$

has eigenvalues $y^{(m)}(kc, u)$ for which representations as entire functions of $u \neq 0$ can be found. The corresponding generalized Fourier coefficints of H, $H^{(m)}$, satisfy

$$H^{(m)}_{uu} + (\sinh u)^{-2} (H^{(m)}_{ww} + H^{(m)}/4) - y^{(m)}(kc,u) H^{(m)} = g^{(m)} .$$

This equation can be analyzed as a spectral series corresponding to the eigenfunctions of the "outgoing" operator

$$(\sinh u)^2 (H^{(m)}_{uu} + y^{(m)} (kc,u) H^{(m)})$$

obtaining a representation in terms of propagation in the w direction (B.Friedman. Comm Pure Appl Math, 1951 ; N.D.Kazarinoff and R.K Ritt, Ann Phys,1959; --------,Arch Rat Mech and Anal,1960)

APPLICATION OF A GENERALIZED LEIBNITZ RULE FOR CALCULATING ELECTROMAGNETIC FIELDS WITHIN CONTINUOUS SOURCE REGIONS

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In deriving the electric and magnetic fields in a continuous source region by differentiating the vector potential, Yaghjian (American Journal of Physics, September, 1985) explains that the central obstacle is the dependence of the integration limits on the differentiation variable. Since it is not mathematically rigorous to assume the curl and integral signs are interchangeable, he uses an integration variable substitution to circumvent this problematic dependence. Here, we present an alternative derivation, which evaluates the curl of the vector potential volume integral directly, retaining the dependence of the limits on the differentiation variable. It involves deriving a three-dimensional version of the Leibnitz rule for differentiating an integral with variable limits of integration, and using the generalized rule to find the Maxwellian and cavity fields in the source region.

Leibnitz's rule, as established in one dimension, introduces a correction term for each variable integration limit. The extension to a three-dimensional volume integral presented here holds for any function of $\bar{r}$ and $\bar{r}'$, and shows that, analogously, one correction term is required per functional limit of the triple integral in each of the derivatives in the curl expression. This generalized three-dimensional Leibnitz rule is then tailored to solve the specific problem of determining electromagnetic fields in the source region by direct differentiation of the vector potential.

In finally applying the generalized expression to calculate the fields, we simply insert the vector potential to evaluate the magnetic field, and then insert the curl of the vector potential to evaluate the electric field. Since the shape of the principle volume can be chosen arbitrarily we choose a convenient pillbox/slab to simplify extracting and evaluating the relevant correction terms in the generalized Leibnitz expression. Reducing the correction terms yields identically the expressions for the depolarizing dyadic previously calculated for an arbitrary as well as for a pillbox/slab principle volume. This process also reveals that the Leibnitz correction terms are directly related to the depolarizing dyadic which represents the difference between Maxwellian and cavity-defined fields.

AN INTEGRAL EQUATION SET WITH REDUCED UNKNOWNS AND KERNEL SINGULARITY

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Traditionally, the numerical modeling of the scattering from a two-dimensional inhomogeneous target involves the discretization and solution of a set of integral equations formulated in terms of three unknown polarization currents across the interior of the scatterer. For computational efficiency, these integral equations must exhibit both a minimal number of unknown current components and integral kernels of low singularity.

An integral equation for the scattering of two-dimensional inhomogeneous objects is developed by replacing the traditional polarization currents with equivalent currents. This integral equation contains only one unknown current component across the interior of the target and another along the target's perimeter. Furthermore, its kernel is an order less singular than the highest kernel singularity present in traditional integral equation formulations. Scattering patterns computed by a numerical code implementation of the reduced integral equation are presented. These are further compared with results generated by numerical codes based on traditional approaches.

COMPACT REPRESENTATIONS OF RADIATION PATTERNS FOR WIRE ANTENNAS USING SPHERICAL MODE EXPANSIONS

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Spherical mode expansions are investigated as a compact alternative to the storing of entire current distributions for the generation of radiation patterns in connection with a large database containing user oriented information on high-frequency (3-30 MHz) antennas for quickly erectable applications. To minimize the data storage requirements, the high resolution current distributions obtained using the method of moments are used to generate truncated expansions of orthogonal spherical modes (Harrington, Time-Harmonic Electromagnetic Fields, McGraw-Hill, 1961). Limitations on the electrical size inherent in the portable application together with the mode cutoff properties (Chu, J. Appl. Phys., vol. 19, 1163-1175, 1948) are expected to provide substantial spatial filtering to reduce the amplitudes of modes with mode numbers, m and n, exceeding certain maxima, M and N, say, where M and N depend on the electrical dimensions.

Alternative approaches for obtaining the modal expansions will be investigated by comparing the accuracy of the resulting patterns and the time required for computation. Far-field values of the transverse electric fields, E_θ and E_ϕ, computed on a spherical surface will be used to generate the modal coefficients through numerical integration. Sampling criteria based on the expected limitations on the spatial bandwidth of the radiation pattern will be explored both to minimize computing time and to suppress discretization artifacts in the resultant patterns. In addition, schemes for computing expansions of the vector potentials as an intermediate step will also be considered.

Fundamental criteria for comparing antennas having widely diverse will also be sought in this study. Directivity, beamwidth, and beam direction, i.e., elevation and azimuth, have dominated in the past. However, if spherical mode expansions are readily available they may serve not only to characterize antennas qualitatively for comparison but also to furnish superior quantitative models for computing path loss and modulation bandwidth.

THE COULOMB GAUGE AS AN ALTERNATIVE TO THE LORENTZ GAUGE IN THE MIXED POTENTIAL INTEGRAL EQUATION FORMULATION

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The electric field integral equation (EFIE) in mixed potential form is widely used in electromagnetic field scattering formulations. Previous authors have derived mixed potential expressions based on the Lorentz gauge. In this paper we present an investigation of an alternative mixed potential formulation incorporating potentials which are derived subject to the Coulomb gauge.

Historically, the Lorentz gauge has been preferred since the vector and scalar potentials are easily decoupled, yielding a pair of inhomogeneous wave equations, one for magnetic vector potential $\mathbf{A}$ in terms of the current density $\mathbf{J}$ and one for scalar potential Φ in terms of the charge density ρ. Similar methods of analysis lead to Coulomb gauge potentials that appear to be coupled. However, by partitioning the Coulomb gauge potentials into solenoidal and lamalar parts, and by taking advantage of the arbitrariness in the defintion of the potentials, a decoupled pair of wave equations can be obtained. However, a price is paid in that the Coulomb gauge vector potential wave equation is in terms of entirely solenoidal current density $\mathbf{J}^s$.

One of the intriguing aspects of the Coulomb gauge is that when sources are radiating in the presence of perfect conductors the scalar potential is a static potential which satisfies Poisson's equation. This is interesting, because certain simple two and three dimensional geometries have known closed form static potentials. A closed form Lorentz gauge scalar potential does not exist for these simple geometries. We will present one such configuration, that of a two dimensional arbitrarily shaped scatterer in the presence of a cylinder, compare the Coulomb and Lorentz gauge analyses and numerical computation time and difficulty.

FOURIER TRANSFORM OF THE GREEN'S FUNCTION FOR THE TWO-DIMENSIONAL HELMHOLTZ EQUATION

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Abstract

This paper describes an efficient method for computational evaluation of the discrete transform of the Hankel function over a 2-D domain. The technique of constructing the transform of the Green's function so as to contain the proper far field behavior does not introduce boundary source elements, and does not employ a "local" radiation boundary condition. Numerical considerations concerning sample-cell requirements and size of the computational box are also presented. The discrete Fourier transform of the Hankel function is required in the course of applying the fast-Fourier transform technique with the conjugate gradient method (FFT-CGM), which is a promising method in terms of numerical efficiency, for solving 2-D scattering problems involving electrically-large lossy dielectric bodies with cylindrical symmetry. The Hankel function of the first kind, of order zero, being the Green's function for the scalar Helmholtz equation in 2-D is an important part of the solution of such open region boundary value problems. Its discrete Fourier transform is required for the application of the FFT-CGM technique. However, the transform contains a delta function requiring special computational procedures.

Tuesday AM

URSI-B Session 34

GAUSSIAN BEAMS

Chairmen: E. Niver, NJIT; N. Wang, Ohio State University

Room: Newhouse A1 *Time*: 8:25-10:10

Hybrid Formulation of High Frequency Propagation in a Tropospheric Surface Duct. I-Rays, Modes and Remainders

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High frequency propagation in tropospheric ducts is modeled conventionally by ray or by mode formulations. The ray formulations are deficient for strongly trapped ray fields with many longitudinal oscillations, and for transitional rays tangential to the duct boundary. The mode formulations require many normal and leaky modes and, in the earth flattened approximation, cannot accommodate large heights outside the duct. These deficiencies can be overcome by a self-consistent hybrid ray-mode representation, wherein troublesome ray angular spectrum intervals are filled with modes and troublesome mode angular spectrum intervals with rays, subject to inclusion of spectral remainders. These concepts are illustrated here for a strong surface duct modeled by an equivalent bilinear refractive index height profile in the presence of a perfectly conducting flat earth. For line source excitation inside the duct, the hybrid ray-mode form is derived rigorously and evaluated asymptotically. It comprises "legitimate" trapped and leaky rays in noncritical ray domains inside and outside the duct, whispering gallery modes in the boundary layer near the surface, and a few leaky modes in the transition region surrounding the upper boundary of the duct. At long propagation distances, the remainders are usually unimportant. The analytical results are accompanied by numerical comparisons.

Hybrid Formulation of High Frequency Propagation in a Tropospheric Surface Duct. II-Rays and Parabolic Propagators

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The hybrid ray-mode formulation in Part I of this presentation involves modes in the narrow angular spectrum domains that define the boundary layers near the surface and near the upper duct boundary, respectively. At long propagation ranges, these narrow angle spectra can be replaced also by propagators derived from the parabolic equation (PE) approximation. This yields a self-consistent hybrid ray-PE form. The PE propagator has the advantage of simple numerical implementation when the duct undergoes weak longitudinal changes, even those that transform it from guiding to antiguiding. The legitimate ray fields likewise adapt to these longitudinal inhomogeneities. The mode-PE equivalence and the resulting ray-PE representation for the boundary layer near the surface is derived and then applied to the model duct of Part I. By demonstrating that the boundary layer fields at long ranges in the longitudinally homogeneous duct can be constructed accurately with the PE algorithm, it is suggestive that the ray-PE format will be useful also for longitudinal variations.

SYNTHESIS OF HIGH FREQUENCY PROPAGATION BY PARAXIAL GAUSSIAN BEAMS: TRAPPED PROPAGATION IN A SURFACE DUCT

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Propagation of high frequency fields as a superposition of Gaussian beams instead of geometrical ray fields has potential advantages in complicated environments because the beams do not fail in ray optic transition regions. While the Gaussian beam method can be made rigorous through self-consistent stacking of displaced and tilted beams on a Gabor phase space lattice, with retention of the full beam spectra, computation is facilitated when the propagation domain is covered by paraxially approximated nontilted beams. The spectral deficiencies introduced by this simplified propagation model depend on the propagation environment. They are examined here for a full or surface duct with an inhomogeneous wave trapping transverse refractive index profile wherein ray optics becomes deficient due to the pileup, at long propagation distances, of the caustics generated by ray species with many undulating refractions around the duct axis for the full duct, or with many refractions-reflections for a transversely bounded surface duct. Even corrections for individual caustics are inadequate to account for this accumulation. The Gaussian beam method provides a potential alternative to overcoming these difficulties. Since the Gaussian beams must be tracked in an inhomogeneous medium, the paraxial approximation, if valid, would offer substantial computational advantages. To test the paraxial beam stacking algorithm, a line source excited surface duct with an exponentially decreasing refractive index profile away from a perfectly reflecting boundary has been considered. A rigorous reference solution can be derived and computed for this case. Rather than dealing with the more complicated pileup of caustics, the investigation is restricted to evaluating the field at the surface in intervals that include successive multiple reflections, and the individual caustics generated thereby. With beam waists referenced to the location of the source, and stacking beams in angular intervals around the source, it is possible, by numerical experiment, to find stacking parameters that reproduce the reference solution surface field well at the first encounter. However, the beams tracked in this manner yield progressively worse agreement for successive reflections. The beam stack can be retuned to accommodate any particular multiple reflection interval, but then it is less satisfactory in preceding and subsequent intervals. Each beam stack does yield a smooth transition across caustics which intercept the surface, and it predicts the transitional fields well when tuned to that interval. Nevertheless, this canonical test reconfirms for another propagation environment the spectral deficiencies of the paraxially approximated beams and the associated lack of a priori predictability. More fully fleshed out spectral methods must be explored to cope with these limitations.

Ray-Mode Analysis of Complex Resonances of an Open Cavity

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and

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Abstract

Complex resonances furnish valuable inputs for classification of radar signatures from irregularly shaped objects. An important class of targets involves open-ended enclosures with exterior-interior coupling. If the interior has waveguide-like properties, modal expansions can model the wave phenomena there, while ray methods can be employed to account for multiple diffraction at the aperture edges, and for wave interactions around the exterior boundary. By self-consistent ray-mode coupling in a hybrid format, one can construct a global resonance equation whose solutions yield the complex resonant frequencies for the composite object. The conglomerate of these full resonances can be better understood by consideration of more easily determined partial resonances, which account for the dominant wave interactions in various frequency intervals. Such partial resonances can be generated by ignoring intermode coupling, external low-Q interactions, etc. These concepts are illustrated here on the prototype configuration of a finite-length plane parallel perfectly conducting waveguide, which is open at one end and terminated at the other. Emphasis is on the lower order resonances where wavelengths are comparable to critical target dimensions. Global resonances obtained by fully coupled interior modes and exterior rays are compared with partial resonances generated by individual uncoupled modes. The latter are found to describe adequately the observed high-Q global resonances near individual mode cutoff. The importance of evanescent modes and of coupling to nearest neighbor modes is investigated, as is the contribution from low-Q interactions around the external circumference.

BEAM DIFFRACTION BY HALF PLANES AND WEDGES: UNIFORM AND ASYMPTOTIC SOLUTIONS

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The complex source point method and the geometrical theory of diffraction are a powerful combination for accurate solutions in high frequency diffraction by local sources. It is well known that the asymptotic diffraction coefficients for half planes and wedges upon which the geometricaal theory of diffraction is based are singular at reflection and shadow boundaries. However when the source has complex spatial coordinates for the beam solution the angle of incidence of the ray which strikes the edge is generally complex and the asymptotic solution is then non-singular. This has been put forward as an advantage of the complex source point method, a proposition which is examined here for half planes and wedges.

When an asymptotic solution for beam diffraction by a half plane obtained with the complex source point method (Green et al., J.Opt. Soc.Am., 69, 1503-1508, 1979) is compared numerically with a simple uniform solution (Suedan and Jull, IEEE Trans. AP-35, 1077-1083, 1987) exact in the far field the limitations of the asymptotic result are evident. Generally the asymptotic result is finite but quite inaccurate in the vicinity of the shadow boundary. Moreover if the diffracting edge of a half plane or wedge lies on the beam axis the angle of incidence of the ray striking the edge is real and the asymptotic result is singular. The asymptotic solutions yield accurate scattering patterns only with directive beams pointed well away from the edge; i.e. when there is negligible edge diffraction. Consequently to avoid inaccuracies due to shadow boundaries a uniform solution is required. This generally involves evaluating Fresnel integrals with complex arguments, but that is readily achieved by conversion to error function integrals and use of standard computer subroutines.

The above comments are illustrated with numerical examples for both half planes and wedges.

Tuesday AM

URSI-B Session 35

ITERATIVE METHODS IN THE TRANSFORMED DOMAIN

Chairmen: C. Butler, Clemson University; K. Michalski, Texas A and M

Room: Newhouse A2 *Time*: 8:25-10:10

A DISCRETE FOURIER TRANSFORM METHOD OF SOLVING DIFFERENTIAL-INTEGRAL EQUATIONS IN SCATTERING THEORY

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This paper presents an accurate and efficient numerical method of solving many differential-integral equations arising from electromagnetic scattering theory. It uses the discrete Fourier transform technique to treat both the derivatives and the convolution integral, which often appear in these equations. As a consequence, this method is extremely simple to implement, uses less computer memory than comparable methods, and yields accurate predictions.

The differential-integral equation is first recast into a periodic form conducive to application of the discrete convolution theorem. Next, the differential operators are approximated by appropriate finite difference operators in the discrete space. The resulting equation contains both finite difference and discrete convolution operators. All these quantities are computed by using the Fast Fourier Transform. Finally, an approximate solution is obtained by employing the Conjugate Gradient Method.

Results which include grazing incidence are presented and compared to experimental data for a 3λ x 3λ metal plate, a 9λ x 9λ resistive plate, and a finite dielectric slab with both electric and magnetic properties. The accuracy of the method is further illustrated by comparing prediction with independent measurements by Ross on a 2λ x nλ metal plate, at grazing incidence. In all cases, agreement is excellent. Finally, numerical comparisons between metallic (or resistive) plates and thin dielectric slabs are also included.

ANALYSIS OF DIELECTRIC SHEETS WITH ARBITRARILY-SHAPED METALLIZATION ON BOTH SIDES USING THE CONJUGATE GRADIENT-FAST FOURIER TRANSFORM METHOD (CG-FFT)

Manuel F. Cátedra[x], Luis Nuño

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ETSI Telecomunicación
Universidad Politécnica de Madrid
28040 - Madrid, Spain

ABSTRACT

An Integral Equation System involving Electric and Magnetic superficial currents is solved by the CG-FFT method to analyze planar dielectric sheets with an arbitrarily-shaped metallization on both sides of the sheet. This technique is computationally efficient as it avoids storage of large matrices and the computing time follows the law t=KNlogN, N being the number of basis functions considered to represent the currents and K being a constant that depends on the computer used. This high efficiency allows to analyze sheets with side lengths of several wavelengths. This technique can be useful to analyze planar antennas and also planar circuitry.

A RAPIDLY CONVERGENT ITERATIVE ALGORITHM FOR ANTENNA ARRAY MUTUAL COUPLING COMPUTATION

J.A.G. Malherbe

Department of Electronics and Computer Engineering
University of Pretoria, South Africa.

The inclusion of the effects of mutual impedance in the analysis and synthesis of antenna arrays is common practice. In conventional analysis, the inclusion of mutual coupling can be done by solving for the element currents through matrix inversion.

In this paper, a method is described in which the element currents are obtained by means of an iterative procedure that leads very rapidly to a solution, and is extremely simple. In the example that will be discussed, it is assumed that the radiators are of a dipole-type, but this is not imperative; also, the dimensions and positions of the radiators are assumed to be known, so that the mutual impedance can be calculated.

The procedure starts with a first cycle, for which it is assumed that the mutual impedances are zero; a starting element current matrix is calculated from this assumption and the properties of the feeding system. Now the active impedance matrix for the array is calculated by calculating for each element the sum of the mutual impedances weighted by the currents in the starting current matrix. This active impedance matrix is then used to calculate the currents flowing in each of the elements, using once again the known feed system. This is called the cycle final current matrix.

For the subsequent cycles, the starting current is chosen to be a combination of the previous cycle starting current and the previous cycle final current; it is shown that the arithmetic mean of the two currents is an efficient combination for the new starting current. After each iteration, an error size is calculated as the sum of the squares of the differences between the final currents of two consecutive cycles. The error size is used as an indication of the convergence of the procedure.

The solution converges approximately as the logarithm of the number of the iteration, and will solve the current distribution of a ten-element array in approximately 20 iterations. The analysis procedure can be run on a personal computer for an array of 20 elements with ease. For larger arrays the internal elements have uniform properties and it is only necessary to calculate the currents for the outside rows.

TOWARDS A METHOD OF DETERMINING THE SUITABILITY OF DISCRETE OPERATOR APPROXIMATIONS FOR CONJUGATE GRADIENT METHOD APPLICATIONS.

D.J.Janse van Rensburg* & D.A.McNamara, Univ. of Pretoria, Pretoria, South Africa

Although in the limit natural phenomena may well vary in discrete steps, the majority of electromagnetic systems in engineering involve "measurements" many orders of magnitude coarser than the elementary quantisation. Models of such systems may therefore justifiably be considered in terms of a mathematical continuum. Calculation however is constrained by the finite precision of computing machines, and thus computational electromagnetics requires some form of discrete sampling of observables and approximation of mathematical operations, irrespective of the technique used. Though not new the conjugate gradient method (CGM), and in fact iterative methods generally, have only recently found increased application in electromagnetics. Through numerical experimentation with the application of the CGM to the conducting thin-wire problem modelled using Pocklington's equation the present authors have found that the convergence rate, the number of sampling points, and indeed the answers to which results converge, are critically dependent on the form of discrete approximations used to represent the Pocklington operator. This has not always been made clear in the literature that has appeared up to now. Similar remarks may be made for other operator equations. This is the <u>first</u> topic discussed in this paper. The <u>second</u> aspect considered is the importance of remembering that differentiation of functions specified by discrete data is performed by fitting (either explicitly or implicitly) some function to the data and then differentiating these functions. From this process we obtain dicrete representations of the derivative type operators which operate only on the discrete data points. Thus, whether we care to admit it or not, use of such discrete differentiation operators "induces" expansion functions for the quantity being operated on, though the unknown being solved for may in the final answer be represented in terms of some complicated combination of these expansion functions. A similar statement can be made for integral operators. Now some way of determining the suitability of a computational approximation to an operator is desirable in order to apply the CGM with more certainty. As its <u>third</u> point the present paper suggests that this is best done in some transform domain. Examples are given to illustrate this point and show how this approach enables one to compare different computational approximations of a linear operator and identify improved representations.

RADIATION FROM A BODY OF REVOLUTION USING THE CONJUGATE GRADIENT METHOD

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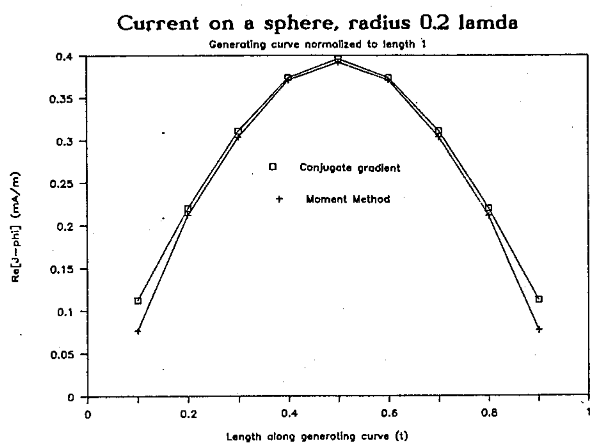
This paper discusses the application of the conjugate gradient algorithm (T.K.Sarkar, IEEE AP-S Newsletter, Aug 1986, pp 5-14) to radiation and scattering problems from perfectly conducting three-dimensional surfaces with rotational symmetry (bodies of revolution [BOR]); previous work has shown how the method can handle certain classes of two-dimensional structures (K.Nayanthara, S.M.Rao, T.K.Sarkar, IEEE Trans. AP, April 1987, pp 451-453). The rotational symmetry of a BOR permits one to use a Fourier (modal) expansion for the unknown surface current in the operator equation relating the surface current to the impressed field; a set of (decoupled) operator equations is obtained for each Fourier mode. The conjugate gradient algorithm is then applied directly to each of the modal operator equations to obtain the surface current.

As an example of the application of the method, we consider the surface current on a sphere excited by an equatorial slot (extending around the whole sphere) with a circumferentially symmetric electric field (1V/m) impressed in the slot. The symmetrical excitation excites only the zero-th order Fourier mode. Results obtained with a computer program written by the author to solve this problem are shown below. These results are compared to results obtained for the same problem using a moment method solution (J.R.Mautz, R.F.Harrington, Appl. Sci. Res. June 1969, pp 405-435). Convergence of the solution with respect to the number of elements used to discretize the generatrix of the BOR has been investigated and these results will be presented. Progress on extending the author's program to handle more general BOR problems will also be reported on at the symposium.



Tuesday AM

Joint AP-S, URSI-B Session 36

SCATTERING AND DIFFRACTION FROM ARRAYS

Chairmen: B. Tomasic, RADC Hanscom; Y. Leviatan, Technion

Room: Newhouse 254 *Time*: 8:25-12:00

8:30	**An "Add-On" Analysis of Large Irregular Strip Arrays** R. Kastner, RAFAEL	See AP-S Dig.
8:50	**An "Add-on" Approach to Determining the Effect of Modification of the Geometry of a Thin Plate on Its Electromagnetic Scattering Properties** R. Kastner, RAFAEL; R. Mittra, University of Illinois	See AP-S Dig.
9:10	**Wave Scattering from Finite Metal Strip Gratings** M. Tsuji, H. Shigesawa, Doshisha University	See AP-S Dig.
9:30	**Scattering by a Finite Periodic Array of Strips** T. Takenaka, Kyushu University	See AP-S Dig.
9:50	**Analysis of Two-Dimensional Electromagnetic Scattering From Non-Planar Periodic Surfaces Using a Strip Current Model** A. Boag, Y. Leviatan, A. Boag, Technion	See AP-S Dig.
10:10	**COFFEE BREAK**	
10:40	**Scattering from Array of Metallic Patches Located on a Curved Surface** W. L. Ko, University of South Florida; R. Mittra, University of Illinois	See AP-S Dig.
11:00	**Canonical Cases of Antennas Radiating In Presence of Structures** B. Audone, M. Balma, AERITALIA	See AP-S Dig.
11:20	**On Transmission Characteristics of an Infinite Plane Grating Embedded in a Dielectric Slab (TM-CASE)** Z. Feng, Nanjing Research Inst. of Electronics Tech.	See AP-S Dig.
11:40	**Perfectly Blazed Dual-Periodic Strip Grating** K. A. Jose, K. G. Nair, Cochin University of Science and Technology	See AP-S Dig.

Notes

Tuesday AM

URSI-B Session 37

TWO-DIMENSIONAL SCATTERING & DIFFRACTION

Chairmen: A. Hizal, METU; J. Volakis, University of Michigan

Room: Newhouse 262 *Time*: 8:25-12:00

ANALYSIS OF ELECTROMAGNETIC SCATTERING BY ARBITRARY SHAPED TWO DIMENSIONAL STRUCTURES WITH LAYERED ANISOTROPIC COATING

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Allen Taflove
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Evanston, Illinois 60201

An alternative approach was reported for the analysis of electromagnetic scattering by an arbitrary shaped two dimensional, homogeneous, anisotropic object located in an isotropic free space medium and excited by a plane wave (B. Beker, K. Umashankar and A. Taflove, 1987 URSI Radio Science Meeting, Blacksburg, Virginia, Abstracts pp. 38, 253). The formulation discussed was based upon rigorous integral equation solution. A set of combined field surface integral equations was obtained for the case of two dimensional objects by treating the surface electric and magnetic fields as unknowns. Both transverse magnetic (TM) and transverse electric (TE) excitation cases were reported for normal plane wave excitation with respect to the axis of the arbitrary cross sectional anisotropic geometry.

This paper reports extension of the analysis and rigorous numerical validation of the electromagnetic scattering as applied to the case of two dimensional structures with anisotropic layered coatings. The combined field surface integral equation formulation previously developed for bulk anisotropic scatterers is applied to the problem of a coated two dimensional dielectric or conducting object. Such coating consists of a single layer of anisotropic material characterized by its permittivity and permeability tensors. The coating, as well as, the core of the scattering structure can have an arbitrary contour including surface discontinuities. By solving the combined field surface integral equations based on the method of moments, the surface current distrubitions along with the corresponding radar scattering cross section for various canonical geometries are presented both for the TM and TE polarizations. The near surface fields and far scattered fields are validated by using alternative methods such as the finite-difference time-domain technique.

The theoretical extension of this procedure as applied to a multi-layered coatings is also presented, and the difficulties in the numerical implementation are pointed out.

H-FIELD SOLUTION OF TE-SCATTERING FROM MULTIPLE PERFECTLY CONDUCTING AND LOSSY DIELECTRIC CYLINDERS OF ARBITRARY CROSS-SECTION

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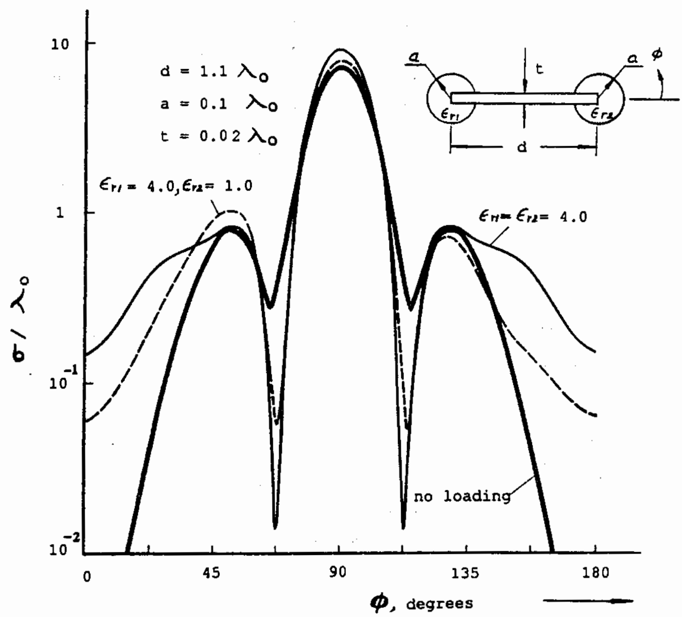
Thomas Knapp
EE Dept. of Rochester Inst. of Tech., Rochester NY 14623.

A simple moment solution is given for the problem of electromagnetic scattering from multiple conducting and lossy dielectric cylinders of arbitrary cross section. The structure is assumed to be excited by a plane wave polarised transverse electric to the axis of the cylinders. The equivalence principle is used to replace the surfaces of the cylinders by equivalent electric and magnetic currents radiating in unbounded media. A set of coupled integral equations is obtained by enforcing the boundary condition on the tangential component of the total magnetic field. The method of moment is used to solve these equations. Point mathcing and pulse expansion functions are used. The figure below shows the monostatic radar cross section of a thin conducting strip loaded by two dielectric cylinders.



A SIMPLE PULSE-GALERKIN FORMULATION FOR THE SCATTERING BY A COATED CYLINDER [1]

Nan Wang

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Department of Electrical Engineering
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This paper treats the two-dimensional problem of electromagnetic scattering by a cylinder of arbitrary cross section and coated with lossy material. The problem is formulated in terms of coupled boundary integral equations, with equivalent sources for the external and internal regions as unknows (R. F. Harrington, AP-S International Symposium Digest,1986, pp 277-280). The fields inside the coating can be considered to be produced by the equivalent sources g_c on the conducting surface and g_1 on the dielectric/air interface, radiating into unbounded homogeneous space filled with the dielectric of permittivity ϵ_r and permeability μ_r everywhere. Similarily, the scattered field can be considered to be produced by equivalent sources g_0 on the dielectric/air interface radiating into unbounded free space. The boundary conditions to be satisfied are the continuity of tangential E and H over the dielectric/air interface, and tangential E=0 on the conducting surface. The coupled integral equations are reduced to a SINGLE integral equation with only the external equivalent g_0 as the independent unknown. Finally, the solution to the resultant integral equation has been obtained by the method of moments using a PULSE-GALERKIN (delta-delta) formulation. As a consequence, the elements of the matrix equation are simple to evaluate. An illustrative example is shown in the following figure. Other examples for dielectric cylinder are also included in the paper.

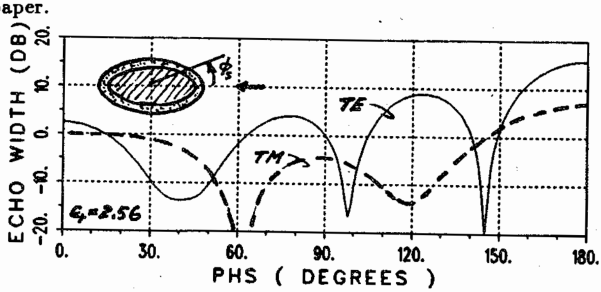

Fig. Bistatic scattering of a coated elliptic cylinder

[1]Work supported in part by Department of Navy, Joint Service Electronics Program Contract N00014-78-C-0049 with the Ohio State University Research Foundation.

AN ANALYSIS OF THE SCATTERING FROM A DIELECTRIC SEMI-CYLINDER*

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Scattering from dielectric or dielectric coated bodies is of great interest to a number of electromagnetics areas. However, the class of problems to which known solutions are available is extremely limited. These solutions are of interest both theoretically and from practical points of view since they provide a basis for physical insight into the scattering/diffraction process. Such canonical solutions are also of great value as test cases when approximate analytical or munerical approaches are under development.

We report the frequency domain solution to the two-dimensional scattering of a cylindrical wave from a dielectric semi-cylinder. This solution to a problem which incorporates a non-trivial dielectric corner is the first of its kind. The fields interior and exterior to the dielectric are expanded in terms of the Bessel function modes and the boundary equations are enforced everywhere. A dual series equation system is obtained for which we have obtained a solution by transforming the dual series problem to an equavalent singular integral equation problem that has a known solution. This solution procedure will be described in detail.

A numerical implementation of this solution has been completed and a variety of results will also be presented. These will include the numerical satisfaction of reciprocity and the boundary conditions; field plots near and away from the dielectric corner; and radar cross-sections as a function of frequency.

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* This work was performed in part by the Lawrence Livermore National Laboratory under the auspices of the U. S. Department of Energy under contract W-7405-ENG-48 and was supported in part by the Applied Mathematical Sciences subprogram of the Office of Energy Research, U. S. Department of Energy, under Contract No. W-7405-ENG-82.

RESPONSE OF A POINT SOURCE NEAR THE INTERFACE OF MULTICYLINDRICALLY LAYERED HALF-SPACES

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Abstract

In this work the response of a point source near the junction of multicylindrically layered half-spaces is found. The inhomogeneity in each half-space is varying as a function of ρ, the radial variable in cylindrical coordinates. This finds numerous applications in geophysical prospecting, optics, etc. A traditional approach to solving this problem is to use the finite element method. But due to the infinite extent of the medium, the finite element method requires a very large amount of storage and computation. Here, we use a semi-analytical approach for the solution of this problem, which is much more economical in terms of computation and storage requirements. The solution is numerical in the transverse direction and analytical in the vertical direction.

First, the eigenmodes in each of the half-spaces are found in the absence of the other. One-dimensional finite element solution of the differential equations describing the transverse field components in each medium is utilized for this purpose. Having found the eigenmodes, the desired source, in particular, a verticl magnetic dipole (VMD), is placed in one of the half-spaces. Eigenmode expansion technique is used to find the response of the VMD in that region. Fields in the half-space containing the source are expressed as the superposition of the direct field generated by the source and the field "reflected" by the discontinuity of the half-space interface. Similarly, the field in the other region is merely the result of the transmission of the direct field generated by the source through the boundary. Matching the tangential fields at the boundary, we obtain the reflection and transmission operators. As a special case of this approach, the results were compared with Sommerfeld's solution of the response of a VMD over a half-space where the two regions are homogeneous. The agreement was excellent. This solution can be applied to any number of layers by systematically expressing the fields in each layer as the summation of upgoing and downgoing waves and matching the tangential fields at each interface to obtain the reflection and transmission operators. The accuracy of the solution in practice is only limited by the computer resources available.

ELECTROMAGNETIC DIFFRACTION FROM A DIELECTRIC-FILLED SLOTTED COAXIAL WAVEGUIDE OF ARBITRARY CROSS SECTION: TM CASE

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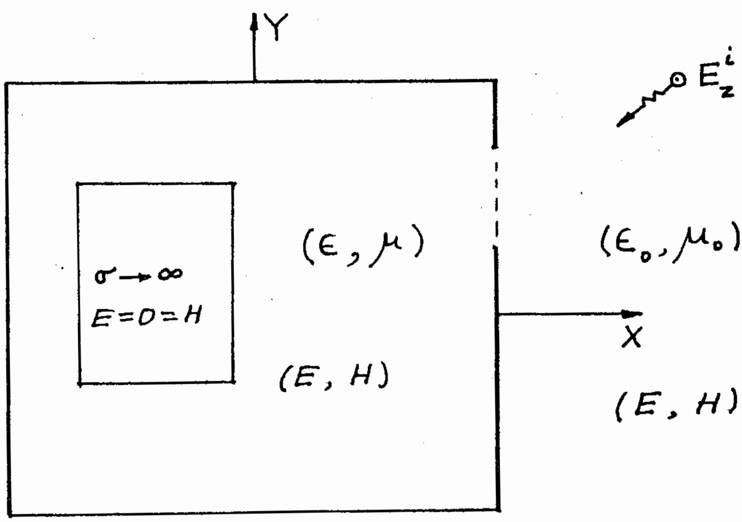
A simple moment solution to the problem of the diffraction of a TM plane wave from an infinite, perfectly conducting slotted cylinder of arbitrary cross section is summarized. The slit cylinder encloses a smaller perfectly conducting, coaxial cylinder of arbitrary cross section, and the space between the cylinders is filled with a dielectric material. The figure below shows a typical geometry of the problem considered. The equivalence principle is used to obtain a set of coupled integral equations for the induced/equivalent surface currents on the cylinders, and the method of moments is used to numerically solve the integral equations. Sample results for the induced current, internal field and scattering cross sections are given. These are in good agreement with some of the available published data.



SCATTERING BY A CIRCULAR CYLINDER PARTIALLY BURIED INTO A GROUND PLANE - TE POLARIZATION

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and
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Abstract

As a continuation of our previous work(T.C.K.Rao and R.Barakat,National Radio Science Meeting,January 1988) which dealt with the TM polarized case,we present the results for the TE polarization for the problem of plane wave scattering by an infinitely long conducting cylinder that is either located on the surface or partially buried into a perfectly conducting ground plane.The total field is expressed as the sum of three different contributions including the incident field,the reflected field and the scattered field from the original cylinder and its image within the ground plane.These contributions are written in terms of cylindrical vector wave functions and making use of the addition theorem for the cylindrical waves,a set of two coupled infinite system of equations for the even and odd mode expansion coefficients is obtained. These coefficients are numerically evaluated by a matrix inversion procedure with no further approximations.The farfield scattering patterns and the bistatic scattering widths are calculated and the results are presented in a graphical form for varying depth,angle of incidence and the electrical radius of the cylinder.

ELECTROMAGNETIC SCATTERING FROM A CONDUCTING CYLINDER PARTIALLY OR COMPLETELY COATED WITH LOSSY MAGNETIC MATERIAL

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The EM wave scattered from a conducting body can be modified if the body surface is coated partially or completely with a layer of lossy magnetic material. In many cases the partial coating is prefered over the complete coating if the performance by the former is comparable with that by the latter.

In this study we consider a geometry of an infinitely long conducting cylinder coated with strips of lossy magnetic materials and being illuminated by an incident plane wave. The induced currents on the cylinder and the scattered fields from the cylinder are to be determined in terms of the parameters of the coating strips. The case of a completely coated cylinder can be treated as a special case. Since an exact solution exists for this case, it may serve as a check for the solution of a partially coated cylinder.

We analyze this problem with two approaches. First we assign a surface impedance to the coating strips and solve the resulting boundary value problem. Secondly we define the equivalent electric and magnetic surface currents on the coating strips and the conducting surface. These surface currents are solved numerically from the coupled surface integral equations. The scattered fields can be computed after these surface currents are determined. With this information we aim to control the scattered fields by the proper design of coating strips on the conducting cylinder.

TE SURFACE-WAVE SCATTERING BY OBSTACLES ALONG ASYMMETRIC PLANAR DIELECTRIC WAVEGUIDE

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Scattering of TE surface waves by obstacles along a planar, asymmetric dielectric waveguide is studied. The layered substrate/film/cover environment, typical of integrated circuits for millimeter and optical wavelengths, provides such a planar guiding structure. When an incident surface wave (maintained by a remote source) interacts with an arbitrarily-located dielectric obstacle along the guiding system, excess polarization currents, associated with the field induced in the obstacle, subsequently excite a scattered field. The latter field is comprised of scattered discrete guided waves and a radiative component. Quantification of the scattering coefficients and relative radiated power is fundamental to understanding electromagnetic interactions in integrated circuits.

The excess polarization current, which maintains the scattered field, is proportional to the product of the induced field and the contrast $\delta n^2(\mathbf{r})=n^2(\mathbf{r})-n_u^2$ of the refractive index $n(\mathbf{r})$ of the obstacle against n_u of the unperturbed guiding structure. Within the obstacle, total field $\mathbf{E}=\mathbf{E}^i+\mathbf{E}^s$ consists of the impressed field of an incident wave augmented by the scattered field (expanded in the complete propagation-mode spectrum of the guiding structure). Rearranging leads to the electric-field integral equation (EFIE)

$$E_y(x,z) - \frac{jk_0}{Z_0}\int_{LCS} \delta n^2(x',z')E_y(x',z')G(x,z|x',z')dx'dz' = E_y^i(x,z)$$

where k_0 and Z_0 are the free-space wavenumber and intrinsic impedance, respectively, LCS designates the longitudinal cross section of the obstacle, and $G(x,z|x',z')$ is an appropriate Green's function (believed new) expanded in the discrete and continuous propagation-spectrum components for the asymmetric planar waveguide.

Numerical solutions to the EFIE lead to the induced field within the obstacle. Scattering (reflection and transmission) coefficients are subsequently calculated in terms of that induced field. Extensive numerical results for various obstacle configurations will be presented. Those results will be confirmed by experimental measurements of induced fields and scattering coefficients at milimeter wavelengths.

Tuesday PM

Joint AP-S, URSI-B Session 40

NUMERICAL METHODS: RADIATION BOUNDARY CONDITIONS

Chairmen: D. R. Wilton, University of Houston; R. W. Ziolkowski, LLNL

Room: Sheraton Regency B *Time*: 1:25-5:00

1:30	**On-Surface Radiation Condition (OSRC) Analysis of Coupling into Open Waveguides and Cavities** J. G. Blaschak, A. Taflove, G. A. Kriegsmann, Northwestern Univ.	180
1:50	**Three Dimensional Electromagnetic Scattering Calculations Using the Control Region Approximation** B. J. McCartin, R. E. LaBarre, United Technologies Research Center	181
2:10	**A Systematic Approach to Improving the Solution Based on the Absorbing Boundary Condition** O. M. Ramahi, R. Mittra, University of Illinois	182
2:30	**PDE Solution Of the Three-Dimensional Vector Scattering By A Body Of Revolution Using An Asymptotic Boundary Condition** R. Gordon, R. Mittra, University of Illinois	183
2:50	**COFFEE BREAK**	
3:20	**On the Accomodation of Edges When Using the On Surface Radiation Condition** R. J. Pogorzelski, TRW	184
3:40	**Application of the On-Surface Radiation Condition Method to Convex Homogeneous Dielectric Scatterers** S. Arendt, K. Umashankar, University of Illinois at Chicago; A. Taflove, G. Kriegsmann, Northwestern University	185
4:00	**An Application of the On-Surface Radiation Condition to the Scattering of Acoustic Waves by a Reactively Loaded Sphere** G. A. Kriegsmann, T. G. Moore, Northwestern Univ.	186
4:20	**A Comparison of Some Radiation Boundary Conditions for Differential Equation Calculations of Scattering** F. X. Canning, Rockwell International Science Center	See AP-S Dig.
4:40	**A Comparison Between The OSRC Approach And The PO Approximation For Solving EM Scattering** J. Jin, J. L. Volakis, V. V. Liepa, The University of Michigan	See AP-S Dig.

ON-SURFACE RADIATION CONDITION (OSRC) ANALYSIS OF COUPLING INTO OPEN WAVEGUIDES AND CAVITIES

Jeffrey G. Blaschak* and Allen Taflove

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Northwestern University, Evanston, IL 60201

Gregory A. Kriegsmann

Department of Engineering Sciences and Applied Mathematics
Northwestern University, Evanston, IL 60201

The problem of a plane wave impinging on the open end of a semi-infinite, flanged parallel-plate waveguide is solved here through application of an asymptotic differential operator previously developed for on-surface radiation condition (OSRC) theory [Kriegsmann, *et. al.* , IEEE Trans. AP-35, 153-161, 1987]. The theory also renders the solution of the associated cavity penetration problem created when the waveguide is terminated by a perfectly conducting plate located a finite distance from the aperture. An operator, analogous to the $\mathbf{B}_2$ operator of OSRC theory, is applied to the field representations valid in the guide aperture and yields an expression for the coefficients in the modal representation of the waveguide fields. Knowledge of the modal coefficients then permits the derivation of a simple expression for the bistatic cross section of the field scattered by the aperture.

Numerical results indicate that the OSRC operator accurately couples the incident plane wave energy into the propagating waveguide modes. The validity of the OSRC modal representation of the waveguide and cavity fields is demonstrated by comparison to results obtained by finite-difference time-domain simulations. Specifically, results are presented in the case of an aperture having $ka \approx 8$ where a is the plate separation. In both the waveguide and cavity cases, excellent agreement is observed for the field magnitude and phase within the structure and for the bistatic RCS excited by plane waves at various angles of incidence. The agreement is significant when one considers the different nature of the solution methods. The value of the OSRC solution is evident in its simple form and modest computational requirements.

Three Dimensional Electromagnetic Scattering Calculations Using the Control Region Approximation

Brian J. McCartin and Robert E. LaBarre
United Technologies Research Center

The Control Region Approximation is a finite difference method that employs flux and shear balances over special control regions called Dirichlet cells. As such, this technique is fundamentally related to the physical conservation laws, in this case Maxwell's equations. The benefits accrued for electromagnetic scattering calculations are the treatment of scatterers of complex shape and composition. Thus any configuration of magnetic and dielectric materials can be studied including loss mechanisms. In previous work (McCartin et al, JEWA, 1988), this technique was fully developed for the special case of cylindrical scatterers. In that paper a wide variety of such scatterers were efficiently and accurately analyzed. In particular, a comparison against test data for a complicated spar-shell airfoil section showed close agreement thus validating the procedure as well as demonstrating the value of two-dimensional simulation tools. In spite of these encouraging results, there remain many geometries of practical interest which require a fully three-dimensional analysis. This paper presents the extension of this technique from two to three dimensions.

The first issue to be treated will be the relative benefits of the various possible representations of the electromagnetic field in three dimensions. The E, H, vector potential, and Hertz potential formulations will be compared and contrasted with emphasis on ease-of-application of boundary conditions and computational complexity. Next we will present the extension of the Bayliss-Turkel asymptotic boundary conditions to the 3D, vector setting. This step is critical in that the quality of the local radiation condition is the determining factor in the efficiency of finite difference/finite element formulations of the scattering problem. With these formulational issues aside we then proceed to extend the discretization procedure to three dimensions. This involves the formation of the Delaunay tessellation associated with an arbitrary set of discrete spatial points and its geometric dual the Dirichlet tessellation. These are then used to discretize Maxwell's equations in a completely general and physically motivated fashion. The discrete equations so generated are then solved by employing the highly developed sparse matrix technology. Consideration will also be given to potential efficiency gains offered by the emerging vector/parallel processing architectures. Finally, the overall computational procedure will be demonstrated on model problems such as the sphere, cube, and finite length cylinder. The proposed algorithm when fully developed holds the potential to allow the calculation of the scattering properties of large, complex, three dimensional targets.

A SYSTEMATIC APPROACH TO IMPROVING THE SOLUTION BASED ON THE ABSORBING BOUNDARY CONDITION

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Electromagnetic Communication Laboratory
University of Illinois, Urbana, Illinois

When finite difference or finite elements methods are used to solve an open region scattering problem, the region surrounding the scatterer must be truncated by an artificial outer boundary. However, such a truncation introduces errors and, in order to reduce their effects, an absorbing boundary condition (ABC) is typically imposed on the artificial outer boundary to make it as nearly transparent as possible to the waves impinging upon it from the interior. In practice, it is desirable to bring the outer boundary as close to the scatterer as possible so as to reduce the number of mesh points, and hence the size of the associated matrix. However, bringing the outer boundary closer to the scatterer reduces the effectiveness of the absorbing boundary condition and increases the error in the solution.

Let the scattered field in the exterior region of a two-dimensional scatterer be represented in terms of a series of outgoing harmonics as follows

$$u = \sum_{n=-N}^{N} a_n H_n^{(2)}(k\rho)\, e^{jn\phi}$$

Then the authors have shown that it is sufficient to require N to be only slightly larger than the ka size of the scatterer, and that if a solution u were constructed by applying the ABC on the outer boundary, only 20 to 25% of the expansion coefficients corresponding to higher order n's will have non-negligible errors, even when the outer boundary is brought to a distance very close to the scatterer. The purpose of this paper is to address the problem of systematically improving the accuracy of these coefficients, derived by using the ABC, by applying a Unimoment type of algorithm. By systematically improving just the results for the higher-order harmonics in the ABC-based solution, this hybrid procedure overcomes the drawback of the conventional ABC method for solving open region problems where the solution is typically refined by moving the outer boundary farther away from the scatterer at a heavy cost of rapidly increasing the number of mesh points. And yet, the hybrid approach derives an accurate solution by solving a much smaller matrix than is required in the Unimoment method, and thus reduces the matrix storage and solution time. Numerical results are presented in the paper to illustrate the hybrid procedure for a number of test problems.

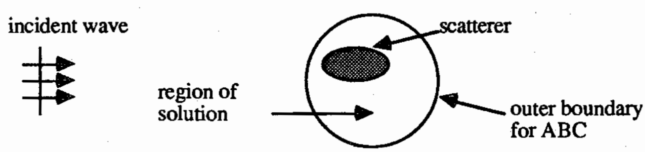

Figure 1. Geometry of the problem

PDE SOLUTION OF THE THREE-DIMENSIONAL VECTOR SCATTERING BY A BODY OF REVOLUTION USING AN ASYMPTOTIC BOUNDARY CONDITION

R. Gordon and R. Mittra*
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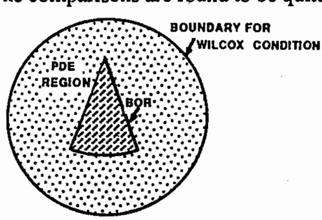
Urbana, Illinois

In this paper, we consider a direct solution of the partial differential equations arising in the problem of electromagnetic scattering by a p.e.c. body of revolution(BOR) which may, in general, be coated with one or more layers of dielectric media. Although it is possible to formulate this problem in terms of the components of the electric and magnetic fields in the region surrounding the p.e.c. scatterer, this calls for a rather large number of unknowns when the dimensions of the scatterer is large. One approach to obviating this difficulty is to employ two scalar potentials and express all of the six field components in terms of these potentials. With certain modifications, the scalar potentials introduced by Morgan and Mei (M & M) for the inhomogeneous BOR problem appear to be well-suited for our purposes, because the continuity conditions at the dielectric interfaces are automatically satisfied by the M &M potentials, a useful feature not found in the Debye potentials.The M & M potentials satisfy a pair of coupled partial differential equations which must be solved simultaneously by enforcing the numerical approximations of these equations at each point in the mesh surrounding the scatterer. An artificial outer boundary must be used to truncate the mesh and this boundary is assumed to be spherical in nature. The Bayliss-Turkel (B-T) type of absorbing boundary condition cannot be conveniently derived for the potentials used in this problem. Instead, an asymptotic boundary condition obtained from the Wilcox's expansion for the scattered field in terms of powers of r^{-1} is used to truncate the mesh at the outer boundary. This boundary condition is even more convenient to implement than the B-T operator, and is readily generalizable to vector fields.

An important feature of this method 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.



Geometry for PDE solution of BOR problem.

ON THE ACCOMMODATION OF EDGES WHEN USING THE ON SURFACE RADIATION CONDITION

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The "on surface radiation condition" (OSRC) was recently introduced as a means of approximating the current induced on a convex two dimensional scatterer. (G.A. Kriegsmann, A. Taflove, and K.R. Umashankar, IEEE Trans. AP-35, Feb. 1987) Taking this approach, one obtains either a differential equation for, or an explicit expression for, the current, depending on the polarization of the incident wave. Several example applications of the technique were presented in the above paper demonstrating the accuracy with which one could estimate the current induced on cylinders and strips. It was noted that further investigation was needed regarding the estimation of the current induced near edges because the OSRC in its present form does not predict the singular behavior known to exist in these regions for general polarization. This paper reports on such an investigation.

In addressing the issue of singular current behavior near edges, it was first noted that the expressions obtained via the OSRC contain an implicit assumption that the radius of curvature of the scattering surface is much larger than the wavelength. Thus, these expressions are inherently unsuitable for representing the singular behavior near edges. The approach reported here involves computation of the residual electric field tangent to the surface of a conducting scatterer on which the OSRC current is flowing. This electric field exhibits singular edge behavior in general. It was intended that the OSRC be used to obtain an estimate of a correction to the OSRC current by considering the residual electric field to be a new incident field (obviously leading to an iterative procedure for improving the current estimate as desired). However, in applying this procedure to the strip problem, it was found that the OSRC in its reported form is not suitable for this application because it implicitly assumes that the scattered field propagates nearly perpendicular to the scattering surface whereas the residual electric field on the strip represents grazing incidence. This led to a modification of the OSRC which permits application in the grazing case and results in a very accurate estimate of the induced current everywhere on the strip including the vicinity of the edges.

APPLICATION OF THE ON-SURFACE RADIATION CONDITION METHOD TO CONVEX HOMOGENEOUS DIELECTRIC SCATTERERS

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The on-surface radiation condition method has been previously shown to be applicable to the case of electromagnetic scattering problems involving two dimensional convex perfectly conducting scatterers. Both transverse magnetic (TM) and transverse electric (TE) polarization cases have been reported with corresponding numerical validations for circular and noncircular conducting convex geometries. Preliminary study was reported as regards applicability of this method to the case of homogeneous, dielectric circular cylinder (K.Umashankar, A.Taflove and G.Kriegsmann, 1986 URSI Radio Science Meeting, Philadelphia, Pa).

In this paper, the on-surface radiation condition method is combined with an analytic continuation scheme to solve the problem of the electromagnetic scattering from an arbitrary two dimensional convex homogeneous, dielectric structure. Specifically, the method consists of applying the OSRC operator to the scattered electric field outside the dielectric object, and using the appropriate dielectric surface boundary conditions in the resulting differential equation to obtain a differential relation between the electric field distribution inside the dielectric object and the corresponding incident excitation electric field outside the object. The interior field distribution is then represented by a suitable modal expansion with unknown modal coefficients. Depending on the given convex geometry, the interior modal expansion is analytically continued throughout the interior of the dielectric scatterer. Finally, the OSRC differential equation is applied to solve for the unknown modal coefficients.

This study reports near and far scattered field distributions obtained for a homogeneous dielectric circular cylinder, and also a dielectric elliptic cylinder for TM plane wave excitation. The resulting surface currents and the far fields are compared with good agreement to those obtained by the integral equation solution.

AN APPLICATION OF THE ON-SURFACE RADIATION CONDITION TO THE SCATTERING OF ACOUSTIC WAVES BY A REACTIVELY LOADED SPHERE

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Although relatively new, the on-surface radiation condition method (OSRC) has been used to study a wide variety of two-dimensional problems. Primarily these problems have been divided into two classes: scattering from conducting or dielectric targets, and penetration into wave guides. The OSRC method reduces the computational work required to solve these two classes of problems by eliminating the need to solve the full Helmholtz equation over the domain of interest. In fact, in the the OSRC method the solution is found simply by solving an algebraic or differential equation along the surface of the target. This is accomplished by applying a differential boundary operator directly on the surface of the target.

This paper will extended the OSRC method to three-dimensional acoustic problems by developing the necessary second order mode annihilating operator and applying it on the surface. The specific case of an acoustic plane wave scattering off an impedance loaded sphere will be examined. The OSRC solution provides an accurate representation of the surface currents and RCS over a wide range of frequencies and impedances. The case of an sphere which has an impedance which varies over the surface will also be presented.

Tuesday PM

URSI-F Session 42

PROPAGATION & REMOTE SENSING ABOVE/BELOW THE EARTH

Chairmen: D. A. Hill, NBS; N. H. Farhat, University of Pennsylvania

Room: Sheraton Comstock A *Time*: 1:25-5:00

Review of Mixed Path Theories in Radio Propagation

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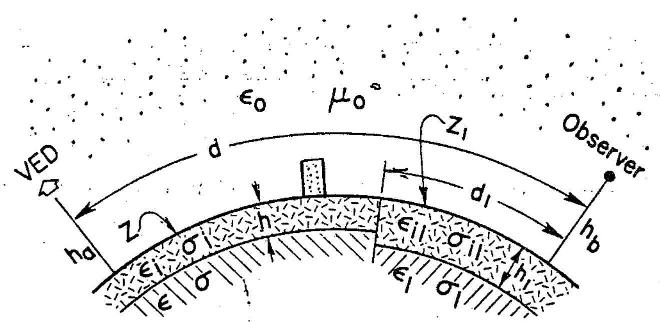
A recurring problem in calculating fields for propagation paths over realistic terrestrial paths is to incorporate THE LATERAL VARIATIONS of the medium properties such as land/sea transitions. Some of the earliest papers on the subject proposed empirical procedures that have stood the test of time (e.g. Millington's ingenious prescription). Methods based on physical optics have also worked surprisingly well in many circumstances. But the integral equation formulations have been most successful particularly in cases where the profile is undulating and there are no significant off path features. In this review we will attempt to describe the scope and limitations of the varied methods that have been put forth to deal with radio transmission for a broad class of such problems including VLF propagation in the earth-ionosphere waveguide for high latitude paths.

In some respects this paper will be an up dating of two earlier ones:(R.J. King and J.R.Wait, Electromagnetic Ground Wave Propagation-Theory and Experiment,Symposia Mathematica(Academic Press),vol.18,pp.107-208, 1976 and J.R.Wait,Recent Analytical Investigations of Electromagnetic Ground Wave Propagation Over Inhomogeneous Earth Models, Proc. IEEE,Vol.62, pp.1061-1072,1974.See also D.A. Hill and J.R.Wait, HF Ground Wave Propagation over mixed land,sea and sea-ice paths, IEEE Trans. Vol.GE-19, No.4 pp.210-217,1981 and J.R.Wait,Chap.7 in "Electromagnetic Wave Theory",Harper and Row, 1986 Edition.



Figure,"Mixed up" path

Submitted to 1988 URSI Meeting, Syracuse Univ.(Comm.F Preference)
(or Joint AP/Ursi F,B?)

WAVE AND PARTICLE BEAMS AND THE GABOR EXPANSION

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Recent work on numerical simulation of beam propagation in inhomogeneous media (waves in refractive-index media, electrons/ions in electromagnetic fields) has incorporated an expansion of the pertinent beam function into a sum of Gaussian beamlets (D.A.de Wolf and J-K.Pack, J.Opt.Soc.Am. A3, 532-535, 1986). The summation is approximate and is based upon the Poisson sum formula.

A more complicated but rigorous approximation is given by the Gabor expansion of a signal into a double sum of equally-spaced Gaussians multiplied by phase exponentials linear in the inverse spacing (M.J.Bastiaans, Optik 57, 95-102, 1980). Recent work by Einziger, et al. (J.Opt.Soc.A3, 508-522, 1986) shows several cases in which the expansion does not require a doubly-infinite set of terms.

Here, we show some relationship of our expansion to the finite-bandwidth case of Einziger, et al. Specifically, we show how the Gabor expansion of a finite-bandwidth (read "smooth") beam intensity, amplitude, or Wigner distribution function reduces to a finite single expansion of Gaussian beamlets when the spacing and sigma width of these beamlets are properly chosen. Some illustrative examples of use will be given.

FIELDS OF HORIZONTAL CURRENTS LOCATED ABOVE THE EARTH

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Radiation from antennas near the earth has been studied by many investigators, and the results for Hertzian electric and magnetic dipole sources are typically cast in terms of Sommerfeld integrals (A. Banos, Dipole Radiation in the Presence of a Conducting Half-Space, New York: Pergamon, 1966). More recently the plane-wave spectrum technique has been used to study transmission into a lossy half space (G.S. Smith, IEEE Trans. Antennas Propagat., AP-32, 232-246, 1984) and to include interactions between antennas separated by a planar interface (D.A. Hill and K.H. Cavcey, IEEE Trans. Geosci. Rem. Sens., GE-25, 422-431, 1987). In this talk we use the plane-wave spectrum technique to compute the far fields and near fields of horizontal electric currents located in a plane parallel to the air-earth interface. This case includes many of the antenna types, such as horizontal loops and dipoles, that are used in detection of buried objects.

We present numerical results for the far fields and near fields of a pair of oppositely directed dipoles. This antenna type is used in detection of buried objects because it has a null in the vertical plane to eliminate the specular return from the air-earth interface. The near fields in the earth are of particular interest for detection of buried objects, and they are calculated by two-dimensional fast Fourier transform (FFT). The FFT evaluation is efficient, and it avoids the use of Sommerfeld integrals. The transmitted field in the earth is enhanced because of focusing, and the primary field in air is partially canceled by the reflected field.

PROPAGATION OF GROUND WAVES OVER IRREGULAR, INHOMOGENEOUS TERRAINS*

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Recent work will be reviewed on the subject of propagation of the total ground wave (space wave plus surface wave) over irregular and/or inhomogeneous terrains, subject to the usual assumptions that (1) there are no surface impedance variations transverse to the path of propagation and (2) backscatter can be neglected.

The most accurate Volterra integral equations for the relative field function (or attenuation function) of the TM_ρ-field of a distributed vertical electric current source or the TM_ρ- or TE_ρ-field of a distributed horizontal electric current source are obtained from appropriate Compensation Theorems.

Volterra integral equations will be presented and their use illustrated in the solutions of practical problems.

* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

TRANSAURORAL HF PROPAGATION ANALYSIS

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ROCKWELL INTERNATIONAL, INC. COLLINS DEFENSE COMMUNICATIONS

This paper presents data which are valuable in assessing the characteristics that a HF communications system experiences in an aurorally disturbed environment. A company-funded transauroral HF experiment [Roesler, et al. MILCOM '87] was performed over the months of September, 1986 to April, 1987. The propagation path, between Barrow, Alaska, and Cedar Rapids, Iowa, was subject to sporadic auroral disturbances. It was thus somewhat representative of typical long-haul high-latitude HF paths in stressed environments.

The primary objective was to quantitatively characterize the HF channel during auroral disturbances using Rockwell Internationals' experimental advanced link-quality analyzer (ALQA) [Bliss, MILCOM '83] and various other computer-controlled devices. Bit error rates of 75-, 300-, 600- and some 1200-baud FSK modems sequentially operating over the same path were measured and recorded. Some of the HF channel parameters determined by the ALQA in real time were signal-to-noise ratio, frequency and multipath delay spread, fading depth, and fading rate. Solar and geophysical data were recorded via satellite from SESC. Local high-latitude geophysical information, auroral-oval plots and data were obtained via the Geophysical Institute at the University of Alaska in Fairbanks.

Propagation models used in the post-collection analysis included AMBCOM, IONCAP, AURORAL OVAL and MINIMUF3.5. The general LUF, MUF, and FOT predictions between the models were compared for various HF path scenarios utilizing the solar geophysical data collected in real time. The capability of AMBCOM to utilize an auroral oval in its 2-D raytrace propagation model, based on the magnetic K index variation, made it ideal for this analysis. This enhanced its usefulness in predicting HF propagation MUF's during auroral disturbances.

The on-going analysis shows various auroral propagation disturbance characteristics in both geophysical parameters and HF channel parameters and performance. Some of these characteristics and their correlations to HF propagation conditions observed will be presented.

LATERAL EFFECTS IN CONTROLLED SOURCE AUDIO FREQUENCY MT

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University of Arizona
Tucson, Az 85721

This paper deals with the problem of modelling controlled source audio frequency magnetotellurics (CSAMT) data. Most CSAMT interpretation is based upon one-and-a-half-dimensional models (i.e. plane layered earth excited by a localized source). To interpret two- or three-dimensional environments, various 1½ dimensional models are pieced together. The more complicated effects of geology are ignored even though they may be significant as we shall show.

A situation in which lateral effects are important is illustrated with data from Avra valley, Arizona (with compliments of Zonge Engineering). A series of CSAMT measurements from this region cannot be explained by 1½ dimensional models. However a model which includes both a sloping interface between valley alluvium and basement, and a localized source does duplicate the observed data. The Avra Valley case study is an example of a situation where the 1½ dimensional model fails. To deal with Avra Valley data, 3 dimensional source modelling and lateral variations of the layering are incorporated.

The perturbation solution method developed here reduces to a related but more restrictive technique (W.J. Hughes and J.R.Wait, Radio Science, 10, 1001-1008, 1975) which only dealt with 2 dimensional undulations of the subsurface interface. A comparison was also made with a scale model measurement for a horizontal loop-loop electromagnetic (HLEM) system over a specially constructed undulating interface for a simulated uneven imperfectly conductive earth.

Finally we discuss a direct interpretation algorithm which combines and extends the suggestions of A.Keceli (Geoexploration, 21, 65-71, 1983). The method allows for parameter estimates of many layer-models using a "layer stripping" procedure developed originally for resistivity surveying at DC.

Submitted to 1988 URSI Meeting, Syracuse Univ. (Comm.F or B is OK)

ELECTROMAGNETIC COUPLING, DILUTION, AND DISTORTION EFFECTS IN INDUCEO POLARIZATION BOREHOLE MEASUREMENTS

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Applied Math. Program and ECE Dept.
University of Arizona /Bldg.104
Tucson, AZ 85721

A basic problem in measuring the intrinsic complex resistivity of the earth is the interfering influence of electromagnetic propagation effects. In a borehole environment the electrodes and the connecting leads are in close proximity. In such situations it is important to deal with the dynamic or time domain solutions in order to ascertain the relative importance of the electromagnetic and electrochemical contributions. Also as discussed below, the geometrical factors of the problem produce "dilution" and "distortion" as described by Wait(GeoElectromagnetism, 1982).

Our first task is to derive expressions for the complete electromagnetic field of an electric current element or dipole located on the axis of a cylindrical borehole cut through an otherwise homogeneous formation with a specified complex resistivity. Following a double spatial integration, we then deduce the mutual impedance between the linear primary circuit and the parallel secondary circuit which together makes up the four electode array configuration. The connecting leads are insulated wires parallel to the axis of the cylinder. We then represent the true complex resistivity of the formation by a Cole-Cole model which allows for the realistic frequency dependence of the formation's electrical properties. For present purposes ,the borehole fluid is represented by a non-dispersive real resistivity for the significant frequency range(i.e. 10^{-2} Hz to 1 kHz).

We exhibit plots of the normalized mutual impedance (or apparent complex resistivity) as a function of frequency for a range of the Cole-Cole model parameters. Overall the masking effects of the borehole is greatest for small electrode spacings and/or when the borehole fluid resistivity is low. But most significant is the effect of the borehole on modifying the frequency dependence of the measured apparent complex resistivity. Such behavior is consistent with the dilution and distortion corrections derived earlier using a quasi-static model(J.R.Wait and T.P.Gruszka IEEE Trans.GE-25 368-372,1987). However the electromagnetic effects swamp the induced polarization response at the higher frequencies (i.e. above 100 Hz). In general such EM coupling is intertwined with the IP dispersion. Various mitigation schemes are discussed and critical assessments are made.

Submitted to 1988 URSI meeting, Syracuse Univ.(Comm F or A)

BEM FORMULATION FOR MULTIPLE HOMOGENEOUS MATERIAL REGIONS OF REVOLUTION

SHEN Xiaoyang, XIAO Yanming
(Xian Jiaotong University, Xian, PRC)

A rotationally symmetric structure, such as a common highly dispersive well-logging environment (Moren et al, 1962, Geophysics, 27,829-858) is illustrated as Fig.1. Loop excitation is assumed, in region 1 and E_ϕ, H_ρ, H_z are considered to be existed. A great simplified I. eq is given (Poggie et al, Computer Techniques for Electromagnetics, 159-182). Applying the concept of BEM and matching the boundary condition on each interface, ten eqs are derived. For example, matching E field on Γ_1, we get the following eq:

$$4\pi E^{inc} = \int_{\Gamma_1} \left\{ j\omega\mu H_{1\rho} (\varphi_1+\varphi_2) + \frac{\partial}{\partial z}(\varphi_1+\varphi_2) E_1 \right\} \cos(\phi-\phi') ds' + \int_{\Gamma_2} \left\{ j\omega\mu H_{2\rho} \varphi_1 + \frac{\partial \varphi_1}{\partial z} E_2 \right\} \cos(\phi-\phi') ds' + \int_{\Gamma_3} \left\{ j\omega\mu \cos(\phi-\phi') H_{3z} \varphi_2 + \frac{\partial \varphi_2}{\partial \rho} E_3 \right\} ds' - \int_{\Gamma_4} \left\{ j\omega\mu H_{4\rho} \varphi_2 + \frac{\partial \varphi_2}{\partial z} E_4 \right\} \cos(\phi-\phi') ds' \quad (1)$$

Where φ_1 and φ_2 are scalar Green's functions of region 1 and 2 separately. In the case of linear element, as Fig.2: $F=\sum_{M=1}^{2} f_{i+M-1} \psi_M(\xi)$

$$\psi_1(\xi) = (1-\xi)/2, \quad \psi_2(\xi) = (1+\xi)/2, \quad -1 \leq \xi \leq 1 \quad (2)$$

Where F may be E, H, z or ρ. By substituting (2) into (1) eqs, a set of block-coupled eqs about the order of 150 is obtained. We don't need to solve the eqs once a time for every sampled point of the well-logging curve which is a function of E fields at R1 and R2. As R1, R2, and T loops move along the axis, only the right hand side of the eqs changes and the left side remains unchanged. Block LU Decomposition and Substitution is an effective way to solve those eqs. The number of numerical computations is about the number of solving one set of such eqs. The BEM approach has a definite advantage over analytic method which can not solve the problem shown in Fig.1 and the conventional FEM which costs too much storage and CPU time. The numerical results show agreement with the methods mentioned above.

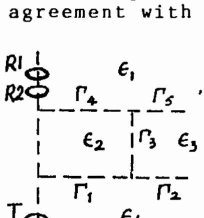

Fig 1

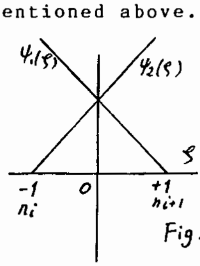

Fig 2

COMPARATIVE ANALYSIS OF WIDEBAND RF TECHNIQUES FOR UNDERGROUND PROBING

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Department of Electrical and Computer Engineering
and Center for Electromagnetics Research,
Northeastern University, Boston, MA,
and Geo-Centers, Inc., Newton, MA

In this paper a comparative analysis is presented for two classes of wideband ground-penetrating radars (GPR) for the detection of buried objects at depths within one or two meters from the surface. These techniques are "time-domain" (TD) and swept frequency (SF). The TD technique employs an extremely short DC pulse shaped to achieve a spectrum centered in the tens to hundreds of MHz and with a half-power bandwidth of the same order as the central frequency. The SF method gives almost uniform spectral coverage over approximately a decade of bandwidth (eg., from 100MHz to 1 GHz).

This analysis focuses on certain specific issues, ie., attainable SNR, depth resolution, antenna directivity, angular resolution and clutter discrimination. The analysis includes effects of the antenna transfer function, ground-air interface effects and the attenuation and dispersion effects of lossy soils. The SNR vs. depth and the depth ambiguity function as a measure of depth resolution capabilities are determined for both TD and SF systems and for various soils encountered in typical applications.

Free-space radar reasoning would predict that depth resolution would be dependent on bandwidth with a somewhat weak-dependance on the signal shape by which that bandwidth is attained. In the GPR context, that prediction is offset by the strong frequency dependence of electromagnetic effects which may radically change the spectrum of the signal impinging on the target and thereby limit the effective bandwidth and, hence, the actual resolution that can be achieved. Numerical results demonstrating that point are shown for some typical soil parameters.

Tuesday PM

URSI-B Session 44

NOVEL WAVEGUIDE CONCEPTS

Chairmen: S. Ghosh, Com. Dev. Ltd.;
H. Shigesawa, Doshisha University
Room: Schine 304A *Time*: 1:25-5:00

FINITE ELEMENT METHOD APPLIED TO E-PLANE METAL INSERT FILTERS.

Mario Chenier *, Michel M. Ney, George I. Costache
University of Ottawa, Ottawa, Ontario, Canada K1N6N5

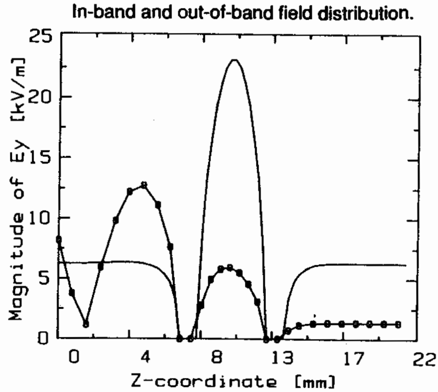
This paper presents a method for solving the field distribution in a E-plane metal insert filter, using the finite element method (FEM). From this, one can determine reflection and transmission coefficients, location and amplitude of field peaks, and current distribution in the inserts. The two latter quantities are useful for estimating the maximum power handling of such structures. To find the peak power handling of such filters, one must obtain their internal field distribution. The FEM is well suited for such a task. A novel approach to the FEM is to solve for the fields in the longitudinal direction, instead of the cross-section of the guide. Boundaries of the problem are located at a sufficient distance from the end metal-inserts such that higher-order modes can be neglected at the interfaces. Letting Ey be denoted by $\underline{\phi}$, applying continuity of tangential E and H fields, and considering interfaces C1 (input) and C2 (output), a functional to be made stationary is:

$$F(\underline{\phi}) = \iint_{\Omega} (\nabla\underline{\phi}.\nabla\underline{\phi} - k_0^2\underline{\phi}^2)\,d\Omega + jK_z \int_{C_1 \cup C_2} \underline{\phi}^2 ds - 4jK_z\underline{E}_0 \int_{C_1} \sin(K_x x)\underline{\phi}\, ds$$

The reflection and transmission coefficients computed agreed well with results from Vahldieck's mode-matching technique [MTT-33, no. 12]. Fig. 1 shows the magnitude of Ey along the guide median, for frequencies in (32.6GHz, continuous line) and out (30.0GHz) of passband region. Input (C1) is at Z=0. Incident power is 1 W. Waveguide type is WR-28.

In-band and out-of-band field distribution.

Fig. 1



IDEAL NORMAL MODE THEORY OF A SERPENTINE CYLINDRICAL WAVEGUIDE

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The axis of a cylindrical waveguide of constant radius and imperfectly conducting walls has a weak harmonic spatial variation about a straight line in a plane. This is equivalent to a cylindrical waveguide with the axis along a straight line and with the radius having harmonic variations both in the azimuthal and in the axial directions. Such a cylindrical waveguide with a doubly periodic wall can be used to convert a TE_{10} mode into a TE_{11} mode selectively in the presence of the other modes. Ideal normal mode expansions of the fields are used to deduce the telegraphist's equations satisfied by the modal voltages and the modal currents. The coupled mode equations satisfied by the suitably normalized modal amplitudes are determined from the telegraphist's equations for these two modes traveling in the forward direction and are analyzed to obtain the basic design details of this mode converter. An example of this mode converter is included. Techniques for the improvement of this basic design are presented.

MODE CONVERSION IN A CYLINDRICAL WAVEGUIDE WITH A PERIODIC STEP CHANGES IN THE RADIUS

Robert A. Schill, Jr.[1] and S. R. Seshadri[2*]
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University of Wisconsin-Madison, Madison, WI 53706-1691

For a cylindrical waveguide with a periodic step changes in the radius in the axial direction and for the fields having azimuthal variation, the propagation of the modal voltages and the modal currents are derived for the transverse magnetic (TM_{mn}) mode. Integral expressions are obtained for all the transfer coefficients. For the practical case of a small relative variation of the radius of the waveguide, the transfer coefficients are evaluated explicitly. The theory is applied to the investigation of the coherent and selective interaction between two forward traveling modes occurring in a mode converter. Representative numerical results are provided to illustrate the operation of a mode converter.

WAVE PROPAGATION IN A CIRCULAR WAVEGUIDE WITH AN IMPEDANCE WALL

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The paper determines the eigenvalues and conditions of propagation of hybrid modes inside a circular cylindrical waveguide with an impedance wall. The analysis allows for different longitudinal and transvers impedances on the walls. A general characteristic equation is derived from which the corresponding characteristic equations for circular cylindrical waveguides with a perfectly conducting wall, a corrugated wall or a dielectric lined wall can be obtained. Finally, it is found that the propagation of hybrid modes in circular waveguides with large radii is independent of the surface impedance.

NEW DEVELOPMENTS IN CIRCULAR OVERMODED WAVEGUIDE

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20742

Microwave transmission using the TE01 mode of a circular waveguide is characterized by an attenuation which decreases monotonically with increasing frequency. In order to achieve low transmission loss, attempts have been made to implement millimeter wave circular waveguide runs with operating frequencies well above the TE01 cutoff frequency (e.g., Bell Syst. Tech. J., special issue on the WT4 Millimeter Waveguide System, vol. 56, no. 10, Dec. 1977). The circular sheathed-helix waveguide consists of a closely wound insulated wire surrounded by a two-layer jacket. The inner layer of the jacket is a lossy dielectric while the outer layer is a good conductor. It is well known that this configuration strongly attenuates the unwanted modes while preserving the desirable transmission characteristics of the TE01 mode. In this paper, we describe a recent effort to design, manufacture, and test sheathed-helix waveguide for use near 3.0 GHz subject to constraints not originally considered in the millimeter wave efforts.

New design features presented in this paper include high-power carrying capability and severe spatial requirements limiting waveguide bend radius and waveguide diameter. Bends, intentional or otherwise, can result in the transfer of energy to unwanted modes. New numerical and experimental results indicate that this is a manageable problem and that our requirements can be satisfied.

Finally, a new metallic transition between one circular overmoded waveguide and four single-mode rectangular waveguides is described and an analytical approach is discussed. The importance of this device lies in the fact that, by inserting four rectangular waveguide bends between two of these transitions, a high power capacity elbow may be formed. Because this elbow has a small radius of curvature, it may be easier to install in some systems than the more gentle sheathed-helix bends described above.

A DETAILED ANALYSIS OF A NOVEL O-TYPE MILLIMETER WAVEGUIDE

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In the millimeter-wave and sub-millimeter-wave frequency range both metallic closed-pipe waveguides and standard optical fibers exhibit prohibitive losses. In order to overcome this limitation a novel hollow, multilayered O-type dielectric waveguide is proposed for use at these frequencies.

In contrast to conventional dielectric waveguides, in this proposed waveguide electromagnetic energy is not guided by surface waves. Instead, guidance is accomplished in the air-core region by reflection of incident radiation from the inner air/dielectric interface. This results in minimization of energy confined to the lossy dielectric material, and hence lower loss.

Dispersion curves from a planer-case approximation justified continued investigation of the layered-cylindrical guide. Investigation of the hybrid modes (angular variation allowed) is presented, in which the form of e_z and h_z are assumed to be travelling waves in all regions. Rigorous analysis of the boundary conditions results in a system of equations, which must be solved numerically for the complex propagation constant ζ. Once ζ is found the fields can be determined by back substitution.

The number of layers used, layer thicknesses, and layer composition are chosen to maximize reflection at the inner interface for a large range of incidence angles. Fabrication techniques perfected in the construction of optical fibers can be adapted to this configuration.

Commission B

ON THE PROPERTIES OF T-SEPTUM WAVEGUIDE

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A small degree of confusion exists concerning the bandwidth characteristics of T-Septum waveguide. This waveguide is similar to ridged waveguide with the exception that the ridges are in the form of a T rather than solid. T-Septum guide was originally proposed and investigated by Mazumder and Saha (IEEE Trans. on MTT, Vol. MTT-33, No. 11, Nov. 1985 and IEEE Trans. on MTT, Vol. MTT-35, No. 2, Feb. 1987). It was shown that the new waveguide is superior to conventional ridged guide with respect to the parameters of dominant mode cut-off frequency and bandwidth. A more recent investigation (Y. Zhang and W.T. Joines, IEEE Trans. on MTT, Vol. MTT-35, No. 8, Aug. 1987) indicates that the bandwidth is considerably larger than was found by the original authors. It was stated in the recent work that the problem was associated with an incorrect identification of the second mode cut-off frequency. The discrepancy between the analyses is as large as 75% for some parameter values and the bandwidth variation as a function of a geometric parameter is dissimilar in shape.

We analyze the T-Septum guide using a variation of the Ritz-Galerkin technique used by both previous groups. We find that our results for cut-off frequencies and for bandwidth track precisely with the original analyses of Mazumder and Saha. We present both sets of previous results along with our new calculations. We also show the field plots of the first few transverse electric modes and illustrate that the usual practice of using the nomenclature of rectangular waveguide (TE_{mn}) to label the modes is misleading.

C.A.D. OF BRANCH-WAVEGUIDE DIRECTIONAL COUPLERS

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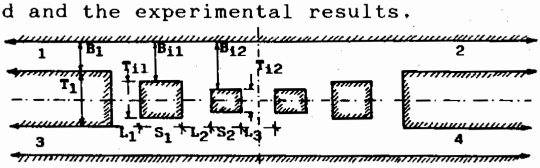
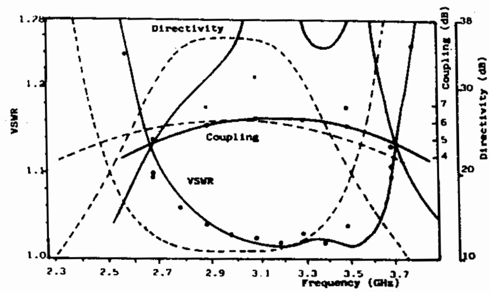
Branch-waveguide directional couplers with four or six ports are widely used as components in the beam-forming networks of contoured beam satellite antennas. The classical design procedure (J. Reed, IRE-MTT, 389-403, 1958) is valid for weak coupling only. However for stronger coupling it is necessary a more accuracy equivalent network of the open E-plane Tee (E. Kühn, AEÜ, 206-214, 1974).

In this paper the Generalized Scattering Matrix (GSM) of generalized 2-port discontinuity concept is employed (R.R.Mansour, R.H.MacPhie,IEEE-MTT, 830-835,1985). This concept allows the analysis and optimization of the branch-waveguide coupler with any number of ports, without geometry limitations and using a sistematic procedure.

The performances of a four-ports five-branch coupler are presented in the figure(L. Mathaei et al. Microwave filters, impedance matching networks and coupling structures, Mc Graw-Hill,835-841). Dashed lines are computed lines in the mentioned reference, points are experimental results, and solid lines are computed values with the method proposed in this paper. A good agreement is observed between this method and the experimental results.





MODAL ANALYSIS OF INDUCTIVE OBSTACLES IN A WAVEGUIDE

CAO WEI*, ZHU XIAOJUN
Nanjing Institute of Posts and Telecommunications, China

The study of inductive metallic posts and diaphragms in a rectangular waveguide has been an area of active research for many years. More recently, a solution for inductive posts and diaphragms of arbitrary cross section and thickness was given by Auda and Harrington using conventional allocation moment procedure (IEEE Trans.,MTT-32, 606-613, 1984). Our paper will here present an alternative approach to attack the same problem based on the characteristic mode theory similar to those ideas suggested by Inagaki (IEEE Trans., AP-30, 571-575,1982). It is shown that this procedure provides an insight to problem and leads to faster convergence than Auda's one.

There are a number of posts and diaphragms located in a rectangular waveguide of z longitudinal axis. These inductive obstacles are assumed tobe perfectly conducting, of arbitrary cross section, and uniform in y direction parallel to the narrow side of the waveguide. The application of boundary condition on the obstacles results in the oprator eguation:

$$T(I_y) = -E_y^i \tag{1}$$

$$E_y^i = \mathrm{Sin}(\pi x/a)\exp(-\gamma_1 z) \tag{2}$$

$$T(I_y) = \sum_{m=1}^{M}\sum_{n=1}^{\infty}\int_{l_m} G_n(x,z|x',z')\, I_y(x',z')\, dl' \tag{3}$$

$$G_n(x,z|x',z') = -\frac{j\omega\mu}{\gamma_n a}\mathrm{Sin}\left(\frac{n\pi x}{a}\right)\mathrm{Sin}\left(\frac{n\pi x'}{a}\right)\exp(-\gamma_n|z-z'|) \tag{4}$$

$$\gamma_n = \left[\left(\frac{n\pi}{a}\right)^2 - \left(\frac{2\pi}{\lambda}\right)^2\right], \quad n=1,2,3,\ldots \tag{5}$$

Where E_y^i is the incident dominant TE_{10} to z mode, M is the number of obstacles, l_m is the contour of the cross section of the m-th obstacle, G_n is the Green's function and γ_n is the propagation constant for TE_{n0} to z mode.

Consider the following operator eigenvalue equation:

$$T^*T(I_y^c) = \lambda I_y^c \tag{6}$$

here the asterisk denotes self-adjointness. All eigenvalues $\{\lambda_n\}$ of the equation should be real and the eigencurrents $\{I_{yn}^c\}$ corresponding to different eigenvalues should be orthogonal according to the theory of linear algebra. These eigendata are obtained by using a Galerkin's method with subsectional pulses as both expansion and testing functions.

Let the induced current on obstacles be a linear combination of the eigencurrents:

$$I_y = \sum_{n=1}^{N} C_n I_{yn}^c \tag{7}$$

The coefficients C_n can be determined by the orthogonality of the eigencurrents:

$$C_n = \left(\lambda_n \|T(I_{yn}^c)\|\right)^{2-1}\langle T(I_{yn}^c), -E_y^i\rangle \tag{8}$$

Itis straightforward to calculate the scattered TE_{10} to z field due to the current I_y. And then the scattering matrix and the impedance matrix, as well as the two-port equivalent network can be found by a conventional way.

Quite a few numerical examples have been done and a good agreement with other available analytical and experimental results shows the correctness and effectiveness of the technique.

Tuesday PM

URSI-B Session 45

WAVE PROPAGATION IN COMPLEX MEDIA

Chairmen: N. Engheta, University of Pennsylvania;
J. Lee, Syracuse University

Room: Schine 304C *Time*: 1:25-5:00

APPLICATION OF THE MODIFIED RADIATIVE TRANSFER THEORY TO SECOND ORDER BACKSCATTERING OF A HALF-SPACE RANDOM MEDIUM

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Syracuse University
Syracuse, New York 13244-1240

In the study of electromagnetic wave scattering from continuous random medium, the radiative transfer (RT) theory is being widely used. However, since the RT theory deals with intensities some phase information of fields is lost. Consequently the RT theory fails to account for part of the scattering process. By combining the concepts of wave theory and RT theory, Zuniga and Kong (J. Appl. Phys., 51, 5228-5244, 1980) formulated the so-called modified radiative transfer (MRT) theory. The MRT equations are constructed using the ladder-approximated Bethe-Salpeter equation along with the nonlinearly approximated Dyson equation. The MRT equations have been solved by Zuinga and Kong using a first order approximation. Under this approximation they have neglected terms associated with the incoherent phase matrices. Physically, this approximation amounts to single scattering of the mean wave. However, the authors have not made any comments regarding the justification for this approximation.

In this paper we obtain a second order solution to the MRT equations for a half-space random medium. We observe that the ratio of the second order terms to those of the first order provides an idea of the magnitude of error involved in making a first order approximation. To that end the effort taken in computing the second order solution has been worthwhile. Besides that the second order solution gives a more clear physical insight into various scattering processes.

We proceed to calculate the backscattering coefficients and cast the expression in a convenient form in order to facilitate comparison. We compare these expressions with those obtained using a corresponding first order approximation. We notice that each term in the first order results has now corresponding second order additions. In the case of anisotropic medium, this includes the "backscattering enhancement" terms, the origin of which is a significant feature of the MRT theory. The second order solution also provides some insight regarding the validity of the first order approximation. The most striking feature of the second order solution is the emergence of cross-polarized backscatter which is indeed a second order phenomenon in an isotropic medium. Finally we illustrate through numerical data many interesting features of our solution by considering typical examples.

SELF-FOCUSING INDUCED BY THE PONDEROMOTIVE EFFECT AND THE THERMAL EFFECT IN THE IONOSPHERIC PLASMAS

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and Research Laboratory of Electronics
Massachusetts Institute of Technology
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ABSTRACT

As a high-power radio wave beam propagates in the plasma media, the nonlinear interaction between the wave and plasmas can lead to the self-focusing of the radio beam. More specifically, in the ionosphere, the nonlinear effects induced by radio waves comprise the ponderomotive force and the thermal pressure force. These forces cause the change of ionospheric dielectric constant along the radio wave path and result in the focusing of radio waves.

In this paper, we examine both the thermal effect and the ponderomotive effect as the two competitive mechanisms in inducing the self-focusing of a radio wave beam in the ionospheric plasmas. The concept of a psudopotential field is utilized to balance the natural diffraction and the self-focusing process of the wave beam and thus the threshold or critical incident power can be determined. We also show that, for the concerned process, the contribution from the thermal pressure force is more heavily dependent on the initial beam width than that from the ponderomotive force. Via solving the nonlinear wave equation near the beam center, we can predict the focal length for the self-focusing process to accomplish. Based on the analytic study, the numerical simulation has also been carried out.

DIFFRACTION BY FRACTAL APERTURES

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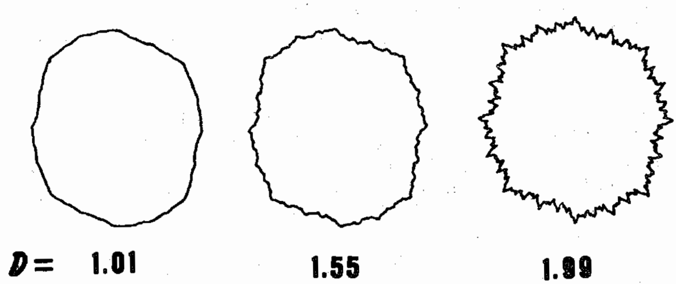
Diffraction of electromagnetic waves by rough apertures modeled by a fractal function is discussed. As shown below, the roughness of an aperture is determined by a fractal dimension D. Explicitly, the edge of an aperture becomes rougher as the fractal dimension increases. Here, the bandlimited Weierstrass function is used as a fractal function to describe a rough aperture.

The paraxial far field diffraction patterns due to fractal apertures are calculated under the physical optics approximation. These diffraction patterns are analyzed by varying the values of fractal descriptors. Of particular interest here is the relation between the fractal dimension D and the speckle distribution. This analysis indicates interesting applications in inverse problems and aperture shaping.



SCATTERING FROM BANDLIMITED FRACTAL FIBERS

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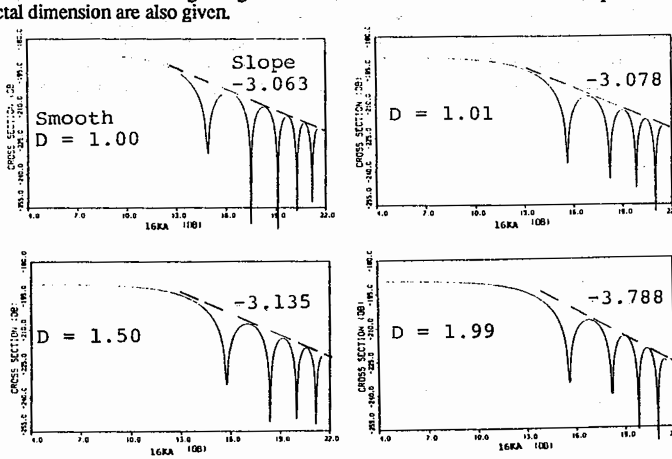
Philadelphia, PA 19104 USA

The fractal concept, introduced by Mandelbrot in the 1970's, complements Euclidean geometry when used to describe irregular or variegated structures such as those that occur in nature. This concept embodies ideas of dilation symmetry, non-differentiability and introduces a fractional dimension. The fractional dimension, denoted the **fractal dimension *D***, exceeds the **topological dimension d** of the structure of interest. For example, the fractal dimension can vary from one for smooth curves to two for irregular area-filling curves while the topological dimension remains unity.

Here the rigid constraints of mathematical fractals are replaced by the more relaxed concept of physical fractals in which the structures of interest maintain dilation symmetry and large but bounded derivatives over a particular regime of interest. This brings to the notion of **bandlimited fractals** which can be modelled using the **bandlimited Weierstrass function.** This has been used previously [D. L. Jaggard and Y. Kim, *J. Opt. Soc. Am. A4, 1055* (1987) and Y. Kim and D. L. Jaggard, to appear, *J. Opt. Soc. Am.*, (1988)] for several problems involving the interaction of waves with fractal structures and will be used here as well.

Here we are interested in the scattering of electromagnetic radiation from fractal fibers. Consider as an example, the backscatter cross-section of a tenuous dielectric cylinder of radius *a* and an axial ratio of 4:1, as a function of size parameter *16ka* in which the projected surface is described by the bandlimited Weierstrass function of fractal dimension *D*. Several cases are displayed below in the figure, ranging from the first in which the surface is relatively smooth ($D = 1.01$) to the last where the surface is highly irregular ($D = 1.99$). The characteristic slope in the fractal regime indicated by the dotted line is dependent on the fractal dimension and indicates the possibility of using this information as a **fractal descriptor.** The absolute value of the slope of the high frequency regime on these log-log plots increases monotonically with increasing fractal dimension. Information regarding the moments of these structures and their dependence on fractal dimension are also given.



PROPAGATION, REFLECTION AND REFRACTION OF ELECTROMAGNETIC WAVES IN CHIRAL MEDIA

Sassan Bassiri*and Charles H. Papas
Electrical Engineering Department
California Institute of Technology
Pasadena, California

and

Nader Engheta
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Pennsylvania

In this talk the radiation characteristics of an oscillating dipole in an unbounded, lossless, chiral medium will be presented. The problem of reflection from, and transmission through a semi-infinite chiral medium will also be discussed. From the constitutive relations $\mathbf{D} = \varepsilon \mathbf{E} + i \xi_c \mathbf{B}$ and $\mathbf{H} = i \xi_c \mathbf{E} + (1/\mu) \mathbf{B}$ and from the time-harmonic Maxwell equations, the wave equation for such a medium is derived. The desired solution of the wave equation is obtained by the Green's function method. The dyadic Green's function and the components of the radiated electric field **E** are found in closed form. The components of the radiated **B**, **D**, and **H** fields can be derived from knowledge of **E** by using the Maxwell equation $\mathbf{B} = (1/i\,\omega)$ curl $\mathbf{E}$ and the constitutive relations. The wave impedance of the medium, the radiation resistance of a dipole embedded in such a medium, and the polarization properties of the dipole radiation are also analyzed. For a chiral-achiral interface, the conditions for the total internal reflection of a plane incident wave from the interface, and for the existence of the Brewster angle will be noted. The effects of chirality on the polarization and intensity of the reflected wave from the chiral half-space will be mentioned and illustrated by employing the Stokes parameters.

THEORY OF CHIRO-STRIP ANTENNAS

Nader Engheta

The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Pennsylvania

The increasing use of Microwave and Millimeter-Wave Integrated-Circuit Antennas and components in telecommunications, radars, and sensing and surveillance systems has focused attention on various problems of propagation of waves with centimeter and millimeter wavelenghts in complex materials used in such devices. Loss of electromagnetic energy in dielectric layers used in microwave and millimeter-wave elements is a major constraint in the design of such elements. In addition, generation of surface wave in conventional dielectric substrates and superstrates in microwave integrated-circuit devices in general, and in microstrip antennas in particular, is an undesirable phenomenon in the performance of such devices. In fact, the presence of surface wave decreases the radiation efficiency of printed-circuit antennas, generates unwanted sidelobes, and reduces the bandwidth of such antennas. New synthetic materials are needed to reduce the energy loss, and more importantly to decrease or eliminate surface-wave propagation in substrates and superstrates used in microwave and millimeter-wave elements.

One such potential material is the Chiral or optically active material. A chiral material is a macroscopically continuous medium composed of equivalent chiral "objects", uniformly distributed and randomly oriented. Such a material is described electromagnetically by the constitutive relations $\mathbf{D} = \varepsilon\, \mathbf{E} + i\, \xi_c\, \mathbf{B}$ and $\mathbf{H} = i\, \xi_c\, \mathbf{E} + (1/\mu)\mathbf{B}$. This form of symmetry, or lack of bilateral symmetry, has been of interest to the scientific community since its discovery by Arago in the early nineteenth century and subsequent experimentation by Biot and Pasteur in the mid 1800's. Recently, there have been several papers by Bohren, Kong, Jaggard et al., Engheta and Mickelson, Silverman, Lakhtakia et al. and Bassiri et al. on the electromagnetic properties of chiral media. Optical activity in a chiral medium differs from the phenomenon of Faraday rotation in, say, a magnetically biased ferrite, by the fact that the former is reciprocal and independent of the direction of propagation whereas the latter is not. Therefore, although chiral media exhibit handedness, they are still isotropic. This is the main difference between chiral media and conventional non-reciprocal anisotropic media.

In this talk, the theory of *Chiro-Strip* antennas, i.e. microstrip antennas with chiral materials as substrates and/or superstrates, will be discussed and novel analytical results will be presented. It is observed that in chiral medium, due to the fact that the eigenmodes of propagation are left- and right-circularly polarized waves, the propagation of surface wave in a rectangular structures such as chiral substrates is drastically different. This leads to different radiation efficiencies, radiation patterns and bandwidths. Since chiral materials exhibit handedness and isotropy, the design of microwave elements with such materials will be considerably simplified.

Use of chiral material in microwave and millimeter-wave integrated circuit antennas and components will open a new chapter in the design of broadband and efficient microwave and millimeter-wave antennas.

CANONICAL ARRAYS AND DUALITY IN CHIRAL MEDIA

D. L. Jaggard, X. Sun* and N. Engheta
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Pennsylvania

Chiral media are characterized by the constitutive relations $\mathbf{D} = \varepsilon\mathbf{E} + i\,\xi_c\mathbf{B}$ and $\mathbf{H} = \mathbf{B}/\mu + i\,\xi_c\mathbf{E}$ where ξ_c is the chirality admittance introduced to take into account macroscopic handedness or optical activity inherent in the media. In addition a chirality impedance and a dimensionless chirality factor are defined in order to describe the wave properties of this medium. As known for some time, this medium supports the plane-wave propagation of circularly polarized waves of opposing handedness and differing wavenumbers. In this talk, the radiation characteristics of a set of simple antenna arrays embedded in an unbounded chiral medium will be discussed. Figure 1 presents the radiation pattern of a turnstile antenna in chiral media displaying the two eigenmodes for positive chiral admittance ($\xi_c > 0$) while figure 2 shows the radiation pattern of a linear array of N-element dipoles spaced a distance d apart along the x axis. The phase shift between array elements is denoted by α. In these figures, the solid line represents the positive mode with right-hand circular polarization while the dashed line represents the negative mode with left-hand circular polarization. It is observed that in the far field, both point and extended sources, whether electric or magnetic, radiate two electromagnetic eigenmodes which are of opposing handedness. However there exist sources that can access only one of the eigenmodes of the medium. Such sources will be presented and discussed. The notion of duality for chiral media, which can be exhibited in a surprisingly simple form will also be discussed. Several applications of the results and array performance in chiral media will also be noted.

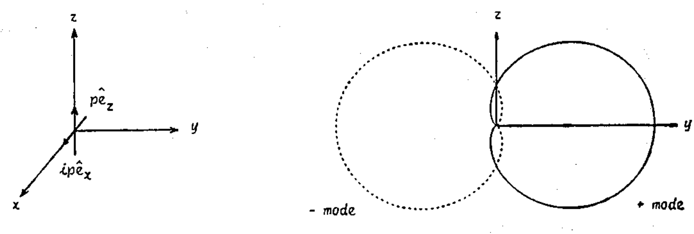


Fig. 1

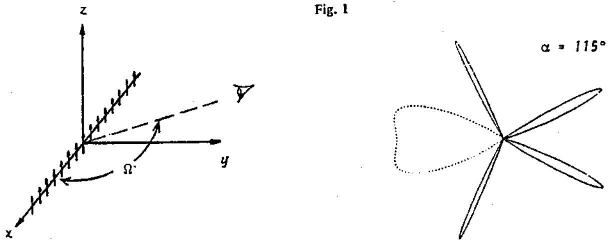


Fig.2

Propagation in Structurally Chiral Media: Intrinsic Anisotropy and Form Chirality

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Department of Engineering Science & Mechanics
and
Center for the Engineering of Electronic & Acoustic Materials
The Pennsylvania State University,
UNIVERSITY PARK, PA 16802.

The most familiar types of gyrotropic media, such as ferrites and magnetoplasmas, are uniaxial. In 1964, Rumsey [IEEE Trans. AP **84**, 83 (1964)] suggested a generalized gyrotropic medium in which several identical uniaxial plates are stacked on top of each other, but their optical axes are variously aligned. The analysis for such a synthetic medium would find considerable use in vision research, as well as in exploring the characteristics of liquid crystals.

In this paper, we will consider a composite slab made up of several identical uniaxial plates. As one goes up the slab, the optic axes of the uniaxial plates rotate in a helical fashion. Therefore, such a slab has intrinsic anisotropy, and it also possesses form chirality. The planewave reflection and transmission characteristics of this arrangement will be examined, and placed in the context of its handedness as well as anisotropy. Special attention will be placed on the field structure existing inside the slab.

THE DISTORTED BORN APPROXIMATION FROM THE METHOD OF SMOOTHING FOR DISCRETE RANDOM MEDIA

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

The distorted Born approximation (also called the distorted wave Born approximation) is a frequently used technique for estimating the incoherent power scattered by a collection of randomly positioned scatterers. Its accuracy is conservatively estimated to be high when the volume fraction density of the scatterers is small. This estimate is based, in part, on the need for knowledge of the average or coherent field in the collection of scatterers and the fact that such information is available when the scatterer density is low. This reliance of the second field moment on the first moment is the reason for the adjective distorted in the description of the method. A primary concern with this approximation is its capabilities and limitations. However, in order to understand these characteristics, it is essential to have a first-principles based development of the approximation. Unfortunately, such a development is not always available because much of it is based on hypothesis. In this paper, an integral equation of the second kind for the fluctuating field scattered by a collection of scatterers is derived based on Keller's method of smoothing. The Born term in this integral equation is or should be equivalent to the distorted Born approximation. While this result confirms that the source of the fluctuating field is the coherent field it does not corroborate the use of an average medium propagator. This means that whereas the conventional distorted Born approximation attenuates the fluctuating field by the <u>two way</u> attenuation associated with the coherent field, this new result shows that only a <u>one way</u> attenuation is appropriate. Other aspects of this integral equation are discussed.

Tuesday PM

Joint AP-S, URSI-B Session 48

ANTENNAS & SCATTERERS

Chairmen: D. Dudley, University of Arizona;
A. Chakrabarty, IIT, Kharagpur

Room: Newhouse 254 *Time*: 1:25-5:00

RADIATION FROM A PIGTAIL-TERMINATED TRANSMISSION LINE PLACED HORIZONTALLY ABOVE A PERFECTLY CONDUCTING GROUND PLANE

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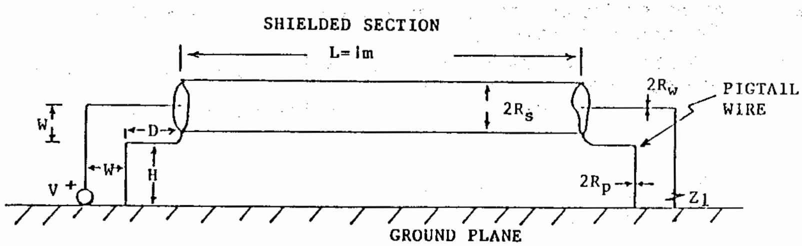
Department of Electrical Engineering
University of Kentucky
Lexington, Kentucky 40506

Pigtail connections play a crucial role in radiation and shielding effectiveness. Consider a coaxial transmission line placed horizontally above ground as shown in the figure below. The outer conductor (shield) is grounded through pigtails. A perfectly conducting line is assumed so that the pigtail effect could be isolated. The line diameter is assumed to be much smaller than its length and the wavelength ($\frac{2Rs}{\lambda}$, $\frac{2Rs}{L}$ << 1). For a perfectly conducting ground plane, image theory applies. The line with its image (replacing ground) is then modeled as a thin-wire antenna. The well-tested moment method computer code "WIRES" is used. Computations are done in the frequency range 25-1000 MHz. Pigtail connections on either or both ends of the line are treated as well as the no-pigtail case (floating shield). Effects of pigtail length, height of transmission line above ground, and load terminations (Zl) are also studied. Computer results of the radiating properties and shield effectiveness of the pigtail-terminated line will be presented.



CALCULATING THE INPUT IMPEDANCE OF SOURCES AT WIRE-TO-SURFACE ATTACHMENT POINTS USING THE NUMERICAL ELECTROMAGNETICS CODE (NEC2)

* T. H. Hubing, IBM Corporation, Research Triangle Park, N.C. and J. F. Kauffman, North Carolina State University, Raleigh, N.C.

The Numerical Electromagnetics Code (NEC2) developed at Lawrence Livermore National Laboratory is a very useful general-purpose moment-method technique for modeling three-dimensional electromagnetic radiation sources in the frequency domain. It models arbitrary configurations of wires, surfaces and wire-to-surface attachments. It is well-documented and relatively easy to use. NEC2 accurately models a wide range of wire-surface configurations, however it does not generally make an accurate calculation of the input impedance of sources on wires near a wire-to-surface attachment. The reasons for this are investigated and some modifications to the algorithm are suggested. These modifications affect the way that the algorithm models wire-to-surface attachments and the way wire-to surface and surface-to-surface interactions are calculated. The resulting code is less efficient and is not recommended in situations where the accuracy of the unmodified code is sufficient. However, the modified algorithm has many important applications. It analyzes many configurations that the unmodified algorithm and other moment-method techniques cannot model accurately.

ANALYSIS OF A THIN WIRE ANTENNA NEAR A HOLLOW, INFINITELY LONG, CONDUCTING CYLINDER - WITH EXPERIMENTAL VERIFICATION

Anthony Q. Martin and Chalmers M. Butler
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Clemson University, Clemson, SC 29634-0915

A solution technique is presented for the current induced on a thin-wire antenna located near a hollow, infinitely long, conducting cylinder of circular cross section. The antenna may reside either inside (interior problem) or outside (exterior problem) the cylinder. The analysis begins with an integral equation formulated in terms of the magnetic vector potential Green's function for an axially-directed dipole near the cylinder. This Green's function consists of an infinite series of Sommerfeld-type integrals whose integrands comprise combinations of Bessel functions. For the interior problem, real-axis integration or an alternate contour is used depending on whether or not the integrand possesses real-axis poles. For the exterior problem, real-axis integration is used exclusively since poles are never present on this path. The integral equation is solved by standard numerical methods when the cylinder's radius is not large electrically.

A long finite-length tube was mounted on a large ground plane in order to obtain corroborative data for the integral equation solution. Measurements were made for the exterior problem only. Measured and computed data are presented for the driving-point admittance of thin-wire and sleeve-fed antennas at various distances from the tube. Preliminary results reveal that the integral equation solutions are accurate.

CURRENT COUPLING BY A WIRE THROUGH A CIRCULAR APERTURE IN THE PRESENCE OF AN INCIDENT QUASI-TEM WAVE

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A major concern to many scientists and engineers is the problem of electromagnetic penetration into an imperfectly shielded system. The specific problem of current penetration along a wire through a circular aperture in an infinite planar screen is considered. Both the wire and the screen are assumed to be perfectly conducting, and the wire is centered in the aperture so that the geometry is rotationally symmetric. An expression for the current is formulated in terms of the electric field at the aperture, and a numerical solution is then obtained by the method of moments. The effects of various parameters such as frequency and aperture size are considered for several observation points on the wire.

An analysis of the source necessary to launch a quasi-TEM wave is also included. Since this source is not realizable by physical means, an approximate source is introduced which can be modelled physically. Results are then presented to determine how well the approximation simulates the ideal case.

ELECTROMAGNETIC COUPLING BY A WIRE THROUGH A CAVITY-BACKED CIRCULAR APERTURE IN AN INFINITE SCREEN

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Tucson, AZ 85721, USA

The problem to be considered consists of a wire passing through the center of a circular aperture in a screen of infinite extent and entering a cylindrical cavity behind the screen. The straight wire follows the axis of the cylinder and is shorted to the end of the cavity. Current on the wire is excited by a source outside the cavity region. This source produces a quasi-TEM wave incident upon the screen. We are concerned with the electromagnetic radiation entering the shielded cavity region. Shielding problems of this type are relevant, for example, in the context of electromagnetic pulse (EMP) hardening design.

An integral equation for the current in terms of the aperture electric field is obtained and then solved numerically using method of moments. We then examine the current on the wire at various locations inside the cavity and study the effects of variations in aperture size or cavity dimensions. Results are presented in both the frequency and time domains. For the transient response we assume a double-exponential pulse excitation. Of principal interest is the resonant behavior inside the cavity.

COMPUTATION OF MAGNETOSTATIC CURRENT DISTRIBUTIONS NEAR WIRE-TO-SURFACE JUNCTIONS

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In the numerical solution of problems involving wires attached to conducting bodies, some assumption must be made about the variation of the surface current on the conductor near the attachment point. If the geometry at the attachment point is sufficiently complicated, this variation cannot be determined analytically, but must be found numerically. In recent studies of such problems, the need has arisen to accurately determine this variation, both to serve as a check on the numerical approach and to synthesize basis functions with the appropriate behavior in the junction region. For triangular patch surface models, wires are assumed to be attached to surface vertices and the current variation only in the attached adjacent triangles is needed. Since this region is electrically small, the problem is equivalent to that of determining the magneto-static current distribution on a certain geometry related to the attachment point geometry. The related geometry consists of a (non-circular) conical surface which is tangent to the surface at the attachment point and which has a semi-infinite filamentary current attached to the cone vertex such that it is tangent to the wire at the attachment point.

In this paper, this magnetostatic problem is formulated and solved numerically. It is shown that the formulation follows as the static limit of the electric field integral equation and involves finding a divergenceless current subject to the boundary condition that the normal magnetic field vanish at the surface of the tangent cone while the filament carries a unit current. Uniqueness of the solution can be proven and it can be shown that the current has only a radial component. The divergenceless condition on the current can be enforced by representing it via an appropriate scalar potential. The integral equation is numerically solved for a number of junctions of interest. For certain junction configurations, results are compared with dynamic solutions for practical junctions.

RESONANCE PHENOMENON IN HOLE EXCITATION OF A WIRE IN A CAVITY

Bailin Ma (Dept. of Electronic Engineering, Shenzhen University, Shenzhen, Guangdong, P.R.China)

In consideration of the electromagnetic excitation of a conducting wire in a conducting cavity numerical calculations are usually made for only one specific incidence frequency and therefore no resonance is observed (D.B.Seidel, IEEE Trans.,Vol.MTT-26,pp.908-914,1978). The problem to be considered is shown in the Fig.. A y-directed thin wire is placed with its axis at x=0 and z=d within the cavity. Two ends of the wire are attached to the top and bottom of the cavity,respectively. The incident plane wave is y-polarized, $\mathbf{E}^i=\mathbf{u}_y E_0$, $\mathbf{H}^i=-\mathbf{u}_x E_0/\eta$. According to (R.F.Harrington, IEEE Trans.,Vol.AP-30,pp.205-212,1982),we begin with two matrix equations,

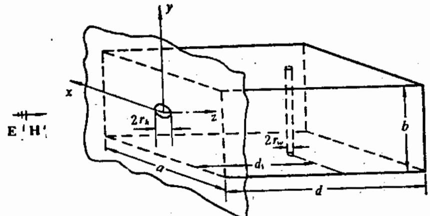

Fig. Hole/wire/cavity excited by plane wave

$$[Y^a+Y^b]\vec{V}+[T]\vec{I}=\vec{I}^{\,i}, \quad [Z]\vec{I}-[T]\vec{V}=0, \tag{1}$$

where $\vec{V}$ and $\vec{I}$ are coefficient column vectors to be determined. The equivalent magnetic current $\mathbf{M}$ over the hole has only x component in the present problem.

$$\mathbf{M}=V_0\mathbf{M}_1 . \tag{2}$$

The wire current J and its expansion functions are defined as

$$\mathbf{J}=\sum_n I_n\mathbf{J}_n , \quad (3a) \qquad \mathbf{J}_n=\mathbf{u}_y\cos(2\pi ny/b),\ n=0,1,2,..... \quad (3b)$$

which are y-directed filaments of electric current along the wire axis and meet the boundary condition at $y=\pm b/2$. The fields due to (3b) in the closed cavity are found by cavity mode expansion. The elements of [Z] and [T] are then obtained. In the calculation of [Z] the thin-wire assumption is applied. In the actual calculation it is found that $|I_n|(n\neq 0)$ are of magnitude order of $10^{-3}|I_0|$ or below. It is not surprising because of the dominant TE_{10} mode excitation of the wire current. Hence,(3a) is approximated as $\mathbf{J}=I_0\mathbf{u}_y$. (4)
Owing to (2) and (4), all matrices reduce to scalars. The calculations are simplified and the frequency can be swept. Resonance is then observed.

The numerical results at resonance are listed in the Tab.,where $(ka)_e$ are given by another approach. The structure can be viewed as a waveguide equivalent circuit consisting of a diaphragm with a hole,a centered cylinder and a short-circuit board. Resonance frequency of the equivalent circuit is evaluated (N.Marcuvitz,Waveguide Handbook,1951) as $(ka)_e$,which is in good agreement with ka from solving (1). On the other hand,it is found in the calculation that $|I_0|$ off resonance are of magnitude order of $10^{-5}E_0a/\eta$. For comparision the I^{fs} in the Tab. denote induced currents in an infinitely long wire of the same r_w and $\mathbf{E}^i$ in free space (R.F.Harrington,Time-Harmonic EM Fields,1961, Eq.(5-110) with sign corrected). It follows that at resonance the perforated cavity no longer shields the wire, on the contrary,the current induced in the wire becomes even larger than that in free space.

Tab. Resonance values for b=0.444a, d=1.2a, d_1=0.7a and r_h=0.03a

r_w	ka	$(ka)_e$	$V_0(E_0a)$	$I_0(E_0a/\eta)$	$I^{fs}(E_0a/\eta)$
0.01a	4.7502	4.7505	0.836	-j6.02	-j0.434
0.001a	4.4980	4.4975	0.932	-j5.06	-j0.258

Wednesday AM - Plenary Session

Chairman: Roger F. Harrington, Syracuse University
Organizer: Tapan K. Sarkar, Syracuse University
Room: Crouse College Auditorium *Time*: 8:25-12:00

8:30	**The History of Electromagnetics as Hertz Would Have Known It** Robert S. Elliott, UCLA	225
9:15	**Radar: From Hertz to the 21st Century** Merrill I. Skolnik, Naval Research Laboratory	226
10:30	**Superconductivity** T.B.A.	
11:15	**Is Relativity Relevant for the Electrical Engineer?** J. Van Bladel, University of Ghent	227

Notes

THE HISTORY OF ELECTROMAGNETICS AS HERTZ WOULD HAVE KNOWN IT

The discovery by the ancients of the electric and magnetic properties of certain materials caused awe and fear, but these feelings gave way to curiosity and the desire to understand. The conception by Peregrinus of a North Pole/South Pole model for lodestone and the identification by Gilbert that the Earth is a giant magnet capped the advances in knowledge up to the end of the seventeenth century.

The eighteenth century witnessed a rich series of discoveries of electric and magnetic phenomena. Gray identified the property of electric conduction and the inverse square law of electrostatics was developed by Franklin, Priestley, Robison, Cavendish, and ultimately Coulomb. Michell showed that the same law applied in magnetostatics and this was reinforced quantitatively by Coulomb.

The pace quickened in the nineteenth century. Volta invented the first chemical battery which permitted Davey and Ampère to flirt with what would ultimately become Ohm's law. Poisson put the laws of electrostatics and magnetostatics in an elegant mathematical framework. The two disciplines were joined by Oersted's discovery of the action of an electric current on a compass needle. Shortly thereafter Biot and Savart, and independently Ampère, couched this discovery in mathematical terms. Oersted's experiment was enlarged by Faraday, who presented to the world the first electric motor. Faraday later demonstrated the converse of Oersted's experiment, showing that a moving magnetic field could induce an electric current, which he quickly followed with developments of the transformer and the electric generator. Faraday's beautiful series of experiments were given their theoretical counterpart by Maxwell, whose equations predicted the existence of as-yet-undetected electromagnetic waves. The culmination of this remarkable train of scientific advances was provided by Hertz, whose experiments validated Maxwell's prediction, an event we now honor a century later.

RADAR: FROM HERTZ TO THE 21ST CENTURY

Merrill Skolnik
Radar Division
Naval Research Laboratory
Washington, D.C.
(paper to be presented at the IEEE AP/URSI 1988 Plenary Session)

The classic work of Hertz in the late 1880s, which experimentally verified the predictions of Maxwell that radio waves and light were governed by the same basic laws, was the first demonstration of the radar principle. It took over forty years, however, for radar to be successfully applied to fulfill a need. After a brief description of what took place in radar from its early beginnings until now, this talk will discuss the factors that have made radar the useful electromagnetic sensor it is today. A review will be given of the major radar applications and the technologies that led to these applications. The significance of radar for civil air-traffic control and military air-defense will be emphasized. Also to be discussed are the current directions indicated for high power radar transmitters, large antennas, waveform design, signal processing, data processing, and sensor integration. Mention will be made of the basic information available from the radar echo signal and its utility for remote sensing and target recognition, the potential for wide-area surveillance from space, and the capabilities and applications of radar operating outside the usual microwave frequency band. Conjectures about the possible nature of radar by the year 2000 will be offered, and an attempt will be made to identify what <u>could</u> be available in future radar if sufficient effort were applied.

Is Relativity relevant for the electrical engineer ?

J. Van Bladel, University of Ghent, Ghent, Belgium

Einstein's first relativistic paper was devoted to the electrodynamics of moving bodies, the aspect of Relativity which is of particular interest to EE's. Relativity allows one to formulate the electromagnetic equations correctly in either inertial or accelerated frames of reference (a well-known example of the latter are axes rotating with constant angular velocity). The paper discusses, in very broad terms, the formulas which allow one to transform fields and sources from one frame to another. The resulting "frame hopping" technique is fundamental for the solution of problems in practice, together with the "instantaneous rest frame" hypothesis, which concerns constitutive equations and boundary conditions. A few typical applications will be discussed. The relevance of Relativity (or lack of it) depends on one's priorities and sphere of activity. The Theory is, of course, eminently satisfactory from an intellectual point of view, and its elements should be part of any course on EM Theory. In particular, Relativity provides a sound basis for formulas which are otherwise presented in the form of "cooking recipes". This holds, for example, for a first-order, low velocity result such as the "Blv" E.M.F. formula, or the justification of the $-(D\phi_i/Dt)$ term in the circuit equation of a moving loop. There are in addition, some relevant radio engineering applications, e.g. to optical rotation sensors, the Doppler effect (in particular at relativistic velocities), MTI systems, the probing of moving thermonuclear plasmas, the Cerenkov effect ... On the whole, though, the relevance is marginal for those of a purely practical mind, who can easily live with rule of thumb methods. The simple example of reflection from a moving mirror will be discussed to illustrate the point, together with the "quasi-stationary" approach to scattering by a moving target. The relevance is greater for EE's in the "power" area, who find a wide domain of application in MHD, magnetic levitation, linear and rotating motors (and generators).

Notes

Wednesday PM

URSI-A Session 50

MICROWAVE MEASUREMENTS & APPLICATIONS

Chairmen: R. King, Lawrence Livermore Lab; B. Cown, Georgia Tech.

Room: Sheraton Amphitheater *Time*: 1:25-5:00

Microwave Measurements on Chiral Composites

T. Guire, M. Umari, V.V. Varadan* and V.K. Varadan
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and
Center for the Engineering of Electronic & Acoustic Materials
The Pennsylvania State University,
UNIVERSITY PARK, PA 16802.

Due to their interesting properties, and the potential for their utilization in microwave applications, chiral media have spawned considerable interest in the last few years. It has been shown by several researchers that when a linearly polarized wave hits a random distribution of helices, the plane of polarization of the transmitted wave is rotated. Rotations of upto 30° have been observed in the past. Because of our interest in chiral composites active at microwave frequencies, we decided to measure their electromagnetic properties. The chiral slabs evaluated by us consist of miniature right- or left- handed steel springs embedded in Eccogel, the total metallic content of the sample not exceeding 1 - 5% v/v. The experimental setup consists of two focussed antennas which face each other, are 60 cm apart, and whose spot foci are 2.5 cm in diameter. The sample is interposed on the common focal plane. The antennas are connected to the HP 8510 network analyzer, and the measurements of the S-parameters are carried out. Time gating is used to discard all other reflections except due to the sample.

The measurements to be reported include the eccentricities of the polarization ellipses of the reflected and the transmitted waves, as well as the rotations of their respective plane of polarization. The reflection, the transmission, and the absorption efficiencies of the sample are also computed. Specific recommendations will be made for the use of these chiral composites.

ATTENUATION MEASUREMENT OF VERY LOW-LOSS DIELECTRIC WAVEGUIDES BY THE CAVITY RESONATOR METHOD IN THE MILLIMETER/SUB-MILLIMETER WAVELENGTH RANGE

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Laboratory Operations
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C. Yeh
Electrical Engineering Department
UCLA
Los Angeles, CA 90024

A dielectric waveguide shorted at both ends is constructed as a cavity resonator. By measuring the Q of this cavity, one can determine the attenuation constant of the guided mode on this dielectric structure. This technique provides a very sensitive way of measuring the attenuation constant of a very low-loss mode propagating along a dielectric waveguide in the millimeter/sub-millimeter range. The complex permittivity of the dielectric waveguide material can also be derived from the measurements. Specific measurements were made at Ka-band for dielectric waveguides constructed of nonpolar, low-loss polymers such as teflon, polypropylene, polypropylene, polyethylene, polystyrene, and rexolite.

50-3
US Radio Science Meeting, Syracuse University, June 6 - 10, 1988

A Free-Space Method for Measurement of Dielectric Constants and Loss Tangents at Microwave Frequencies

V.V. Varadan *, D.K. Ghodgaonkar and V. K. Varadan
Department of Engineering Science & Mechanics
and
Center for the Engineering of Electronic & Acoustic Materials
The Pennsylvania State University,
UNIVERSITY PARK, PA 16802

For measurement of dielectric properties of ceramic and composite materials of plate shape, we have developed a free-space measurement system in the frequency range of 14.6-17.5 GHz. The key components of the measurement system are spot-focusing horn lens antennas, HP 8510B microwave network analyzer and an HP 9836 computer. Because of the far-field focusing ability of horn lens antennas, the free-space measurements can be made at microwave frequencies in a relatively compact and simple measurement set up. The complex reflection coefficients are measured by inserting a perfectly conducting plate behind the plate of unknown material at the focus of the lens antenna. By implementing an algorithm which finds the zeros of the error function, the dielectric constants and loss tangents are calculated from the reflection coefficients.

The inaccuracies in free-space measurements due to diffraction from the sample were minimized by satisfying the condition $D > 3d$, where D and d are the minimum transverse dimension of the plate and the beam width of the antenna at the focus. The time domain band-pass gating feature of HP 8510B and TSD (through,short and delay) calibration technique are being used to eliminate the effects of undesirable multiple reflections. The measurements to be reported include the dielectric constants and loss tangents of several ceramic and composite materials.

This free-space method is particularly suitable for non-destructive and contactless dielectric measurements of bulk materials. For measurement of dielectric properties under high temperature, free-space method is superior to conventional waveguide techniques because it obviates the need for a complicated sample holder.

FREE SPACE DIELECTRIC PROPERTY MEASUREMENTS OF COMMERCIAL RADOME COMPOSITE MATERIALS

Ms. A. H. MacDonald* and Dr. R. L. Moore
Georgia Tech Research Institute
Georgia Institute of Technology

The dielectric properties of commercial radome composite materials have been measured in the 26.5 to 100 GHz frequency range using Gaussian beam horn-lens antenna systems. The Gaussian beam profile is particularly convenient since the Gaussian shape is preserved throughout the system. Conical horns with corrugations in the wall tend to have very weak sidelobes in their antenna patterns and can be empirically designed to yield an approximately Gaussian shape to the field intensity across the beam. Although the horn is primarily responsible for launching the Gaussian beam, the lens also plays an important role. The first half of the lens is designed to establish a plane wave front in the center of the lens; the second half of the lens focuses the Gaussian beam and forms a beam waist having a planar wavefront. Transmitting and receiving horn-lens systems were used to measure transmission coefficient, from which dielectric properties were calculated. The following paper describes how the Gaussian profile beam was planned, how the lenses and horns were designed, and the resulting dielectric properties of the commercial radome composite materials.

Dual Six–Port Reflectometry
A Second Generation.

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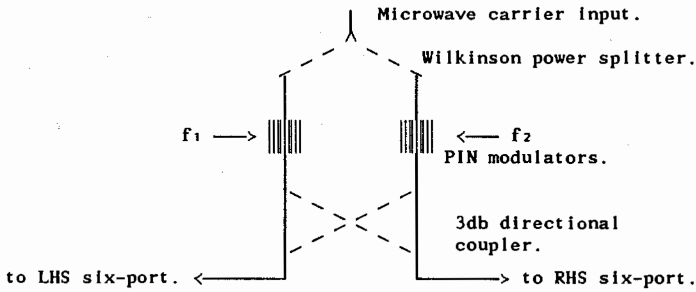
University of HULL.
Cottingham Rd. HULL .HU6 7RX.
United Kingdom.

Abstract.

A new technique Biphase–Bimodulation is introduced. This new technique allows the burden of mechanically precise phase shifters and attenuators to be eliminated from dual six–port reflectometer designs. Calibration requirements are simple, a five standard Thru–Delay and Match technique is sufficient. Measurement performance will allow quasi–real time evaluation of scattering parameters.

Overview.

The diagram illustrates a simple Biphase–Bimodulation element.



Essentially the Biphase–Bimodulation element introduces a microwave carrier to the dual reflectometer that consists of two components. For the LHS six–port, the microwave carrier consists ideally of a 0^0 phase shift labelled with the audio tone f_1 and a 90^0 phase shift labelled by the audio tone f_2. For the RHS six–port the microwave carrier is simarlary composed except the audio tones f_1 and f_2 label opposite phases.

Labelling of the microwave carrier components introduces a <u>degree of independency</u> that allows <u>each</u> six–port to be considered as <u>two individual reflectometers.</u> This independancy allows the four scattering parameters of an unknown device to be evaluated.

The technique has been christened Biphase–Bimodulation since two phases and two modulation frequencies are impressed upon the microwave carrier. Measurement performance comparable to heterodyne network analysers may be expected using this new technique.

Abstract submitted to the URSI radio science meeting commision A.
"Microwave and Millimeter wave measurements."

TECHNIQUES FOR EFFICIENT REVERBERATION CHAMBER COUPLING MEASUREMENTS

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ROME RESEARCH CORPORATION
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Shielding effectiveness (coupling) measurements are currently performed as part of the High Power Microwaves (HPM) characterization of a system. This paper presents the results of the evaluation of several techniques designed to increase the efficiency of shielding effectiveness measurements in a high Q reverberation chamber. The validity and effectiveness of stirrer rotation techniques, single band broad-band spectrum techniques, and multiple band spectrum techniques as implemented in the Rome Air Development Center (RADC) reverberation chamber are discussed.

A CALCULATION OF MEASUREMENT ERRORS ARISING FROM AIRGAPS IN DIELECTRIC/MAGNETIC REFLECTOMETER MEASUREMENTS

Dr. E. Kuster*, D. Acree, and Dr. R. L. Moore
Georgia Tech Research Institute
Georgia Institute of Technology

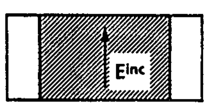
Reflectometer techniques are often used to measure the permittivity ε, and permeability μ, of materials, (J. P. Montgomery, "Measurement of Complex Permittivity and Permeability Using Waveguide Techniques," 1983 International Antennas and Propagation Symposium Digest, Vol. II). Since machining of the samples is not perfect, small airgaps often remain between the sample under test and the transmission line containing the sample. The gap can result in excitation of higher order modes in the region of the sample, and these effect the dominant mode reflection coefficient which is used in determining material parameters. The error in reflection coefficient implies a measured error in material parameters.

This paper will present a modal analysis to predict the dominant mode reflection and transmission coefficients for rectangular, circular, and coaxial transmission lines, partially filled with a dielectric/magnetic plug. The analysis is then used to define error bounds in the measurement of materials with a range of complex permittivities and permeabilities. The material parameters will range over both high and low loss materials. The calculations will include airgaps perpendicular, and parallel, to the incident electric field as indicated below.

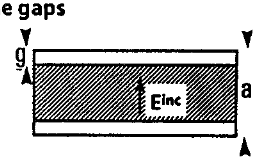
WAVEGUIDES WITH GAPS

- **Rectangular Guide (TE_{01} Incidence)**

E-plane gaps

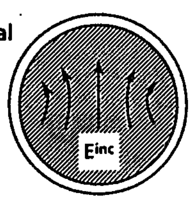


H-plane gaps

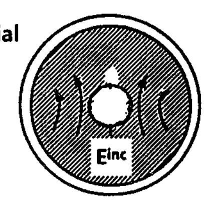


- **Circular Guide (TE_{11} Incidence)**

Cylindrical



Coaxial

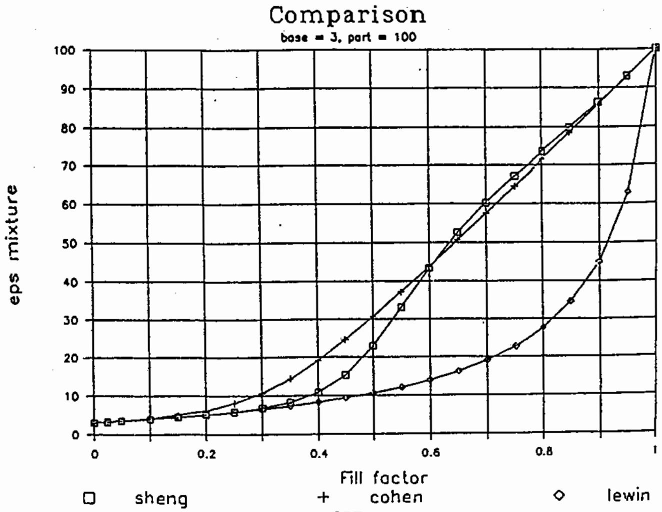


A COMPARATIVE STUDY OF DIELECTRIC AND MAGNETIC MIXTURE THEORIES AT MICROWAVE FREQUENCIES

W. M. Robbins and Dr. R. L. Moore*
Georgia Tech Research Institute
Georgia Institute of Technology

The accuracy of four published theories of mixtures is evaluated by comparing predicted constitutive parameters with the measured data of ferromagnetic/polymer and ceramic/ceramic composites. Effective Medium Theories (EMT) as presented by Cohen (Physical Review B, Vol. 15, p. 5712, 1977), Sheng (Physical Review Letters, Vol. 45, p. 60, 1980), and Chylek (Physical Review B, Vol. 27, p. 5098, 1983) are compared to the Maxwell-Garnett Theory (MGT) as presented by Lewin (IRE, Vol. 94, p. 65, 1947). For two component mixtures, with permittivities ε_1, ε_2, and $\varepsilon_1/\varepsilon_2$: < 10, all four theories are found to give equivalent performance. Each predicts permeability with comparable accuracy since $\mu_2/\mu_1 < 3$. However, for spherical particulates of conductive ferromagnetic powders, the MGT fails for volume fill factors above 25%. At volume fill factors below about 20%, all four theories predict values below the measured permeability and permittivity. At the low fill factors there is reason to believe that there is clustering by the particles, thus making pair-cluster theory for elongated, fibrous particles more accurate than the theory for spherical particles dispersed in a matrix. Further studies will be needed to resolve the differences between theory and measured results.

The theoretical effects on the onset of percolation in the mixture is presented for non-spherical particulates and as a function of particle size distribution. An increase in depolarization, or an increase in particle size distribution, can bring about a reduction in the volume fill factor needed to reach percolation.



Suggested topic for URSI: Microwave and millimeter wave measurements.

FAR FIELD RF SHIELDING EFFECTIVENESS OF MULTILAYERED METAL COATED WINDOWS: UNIFORM THEORY AND MEASUREMENTS.

*Vaessen W.T.E., Dyk J., Vorst v.d. A.
University of technology Eindhoven, the Netherlands, PO Box 513, 5600 MB

Metal coated windows are widely used for increase of far field RF shielding effectiveness. The (near-as well as) far field RF shielding properties of single metal coated windows are investigated by several authors. Their, on transmission line theory based, approximate formulea for the far field RF shielding effectiveness of a single metal coated window, predict a frequency independent behaviour.

RF shielding effectiveness of single- and multilayered metal coated windows have been investigated both theoretically and experimentally. (See fig.1 for test cage) Both theory and experiments state a frequency dependent behaviour of the far field RF shielding effectiveness, due to multiple reflections inside the "electrically thin" metal coatings. Unlike previous theoretical investigations, no approximations have been taken into account, accept for the determination of the resistivity of metal coatings of thicknesses smaller than the mean free path of electrons in bulk metal.

In spite of the fact that electrically thin metal coatings have electrical (as wel as optical) properties far from bulk material, a straight forward model of homogeneous thin metal layers is in good agreement with experiments.
Multilayered metal coated windows produce higher RF shielding effectiveness than single coated windows with the same total metal thickness.
Some attention has been paid to the optical properties of thin metal layers, because light transmittance is an important factor in the design of coated windows.

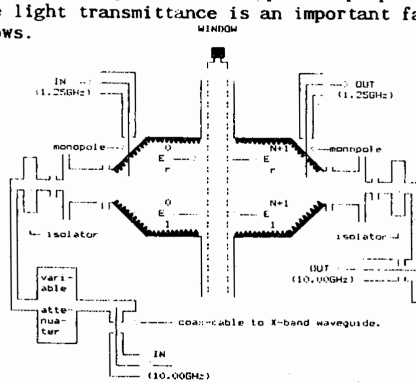


Fig. 1: Cage for RF shielding effectiveness measurements for X-band frequencies and L-band frequency 1.25GHz .

Wednesday PM

URSI-B Session 52

WAVEGUIDE & TRANSMISSION SYSTEMS

Chairmen: L. Gruner, Monash University;
S. Seshadri, Univ. of Wisconsin

Room: Sheraton Regency B *Time*: 1:25-5:00

ELECTROMAGNETIC PROPAGATION IN CURVED S-SHAPED DUCTS WITH PERFECTLY CONDUCTING AND ABSORBING WALLS

Kenneth J. Baumeister
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Lewis Research Center
Cleveland, Ohio 44135

Electromagnetic propagation in curved ducts plays an important role in many practical physical systems. In microwave power generation systems for example, bends or corners are required to alter the direction of the wave. Since curves or corners represent discontinuities, reflections from bends can be significant. To better understand the electromagnetic transmission properties of a bend, a finite element Galerkin formulation has been developed to study wave propagation in curved S-shaped ducts. Both perfectly conducting and absorbing walls will be considered.

The derivations from Maxwell's equations assumed that the material properties could vary with position resulting in a heterogeneous variable property two dimensional wave equation. This eliminated the necessity of specifying interface conditions between different materials. Consequently, complex structures can be easily modeled simply by changing the property of elements in the finite element domain. The reflection and transmission at the entrance and exit of the curved duct are determined exactly by coupling the finite element solutions in the curved duct to the eigenfunctions of an infinite, uniform, perfectly conducting duct.

The numerical formulation is relatively simple to use and appears to give very accurate results. Example solutions are presented for a doubled mitred and S-ducts of various lengths and with perfectly conducting and absorbing walls. The length of the S-duct is found to significantly affect the reflective characteristics of the duct. For a plane wave in a doubled mitred bend, large reflection coefficients are shown to occur near the duct mode cut-on frequencies. Also, wall curvature is shown to greatly enhance the absorptive properties of a duct with an absorptive wall.

CHARACTERISTICS OF DIELECTRIC LOADED WAVE GUIDES AND SHIELDED MICROSTRIPS USING FINITE DIFFERENCES FREQUENCY DOMAIN TECHNIQUE

MOSHE MANELA,* TAPAN K. SARKAR AND E. ARVAS
Syracuse University, Electrical Engineering Department
Syracuse, N.Y. 13244

This paper presents a dynamic finite difference frequency domain for efficient solution of dielectric loaded waveguides and microstrips.

We present hollow waveguides of arbitrary shape, dielectric loaded waveguides, and shielded microstrips having one or more metal strips.

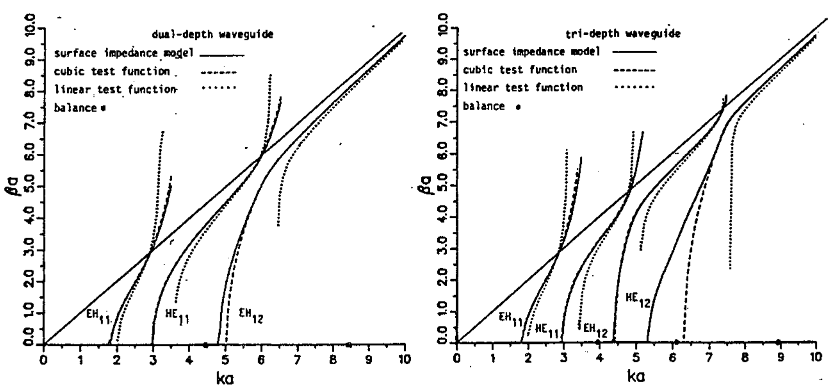
The dielectric loaded wave guide is also solved analytically and the numerical and analytical solutions are compared. For the microstrip case we also solve the Laplace equation using finite differences and get the static solution. It is compared with Quasi Static mode of the dynamic solution when frequency goes to zero.

In the process we face the problem of spurious modes. This problem cannot be eliminated, but we suggest ways of tackling it satisfactorily.

Markku I. Oksanen
Electromagnetics Lab.,Helsinki University of Technology, Espoo,Finland

In this report a circular corrugated waveguide with dual- or tri-depth corrugations is analysed. The method is based on the theory of nonstandard eigenvalues and variational principles (I.V.Lindell,IEEE,MTT-30,1194-1204, 1982). A single-depth corrugated waveguide has been solved by the method earlier (I.V.Lindell et al.,IEEE,MTT-31,520-526,1983).

A stationary functional for the boundary susceptance is derived in terms of the longitudinal fields. The fields can be approximated by trial functions, which for EH_{1n} or HE_{1n} modes are odd polynomials multiplied by $\cos\phi$ or $\sin\phi$. Here, linear and cubic functions with one optimizable parameter in the latter were seen to be sufficient. The magnetic field coefficient must also be determined from the functional. Both parameters can be optimized analytically. The advantage of using a linear function is that the dispersion relation has now an analytical expression. The equivalent admittance of the corrugation wall consists of the series combination of the admittances of the adjacent slots. A first example is a dual-depth guide, where the ratio of the slots equals to 1:2. The cubic function gives very accurate results, whereas the linear function can be used only near the balance frequencies. The solid curve has been calculated by appling a surface impedance method. When a space-harmonic analysis was used, the variational results deviated from these less that 0.05% in the regions of interest. In a second example the slot depths have been chosen to correspond to frequencies 12.5GHz, 19.7GHz and 29.7GHz taken from satellite communication experiments. Again, an excellent performance is obtained.



Dispersion curves in a dual- and in a tri-depth corrugated waveguide.

MODE SPECTRUM OF WAVEGUIDES USING A GENERALIZED MODE MATCHING TECHNIQUE

Dr. L. Gruner, Dept. of Electrical Engineering, Monash University, Clayton 3168, Australia

Consider a uniform homogeneous waveguide having a cross-section bounded by segments, which are parallel to the two transverse axes of an orthogonal cylindrical system of coordinates. The waveguide may be hollow or comprise inner conductor(s) bounded by segments parallel to the above transverse axes.

Then, if the cross-section is divided into two domains in such a way that the common boundary is parallel to either of the two transverse axes and moreover the electric (magnetic) field can be represented as a suitable Fourier series, then the TE as well as TM mode spectrum (and field distribution) can be calculated with the aid of formulae of the form

$$\sum_n \sum_m A_m \{ g_m^2 \sum_\ell \frac{f_\ell^1 < \phi_\ell^1, \phi_m^2 >< \phi_\ell^1, \phi_n^2 >}{f_\ell^2 < \phi_\ell^1, \phi_\ell^1 >} - \delta_{nm} g_m^1 < \phi_m^2, \phi_m^2 > \} = 0$$

The problem can be (and has been) solved for a large number of different cross-sections, including the rectangular coaxial waveguide (L. Gruner, IEEE Trans. MTT-15, 483-485, 1967); when extended to cross-sections comprising three domains, several other problems can be solved, including the determination of the mode spectrum of crossed rectangular structures (L. Gruner, IEEE Trans. MTT-28, 622-627, 1980).

DYADIC GREEN'S FUNCTIONS FOR A RECTANGULAR WAVEGUIDE FILLED WITH TWO AND THREE DIELECTRICS

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Department of Electrical Engineering and Computer Science
The University of Michigan
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The Fourier integral representations of the dyadic Green's functions for a rectangular waveguide filled with two dielectrics have been presented by C-T Tai (to be published in Journal of Electromagnetic Waves and Applications). This work is reviewed starting with the vector wave functions for a parallel plate waveguide. The method of scattering superposition is then applied and the boundary conditions evaluated to construct the integral expressions for the two dielectric filled rectangular waveguide.

His resulting form of the integrand appears to involve branch-points which greatly complicates its evaluation. However, by transforming the expressions to another form, it is shown that these points are neither branch-points nor poles of the integrand. The integration then reduces to a residue series which is then much easier to evaluate.

Using the same approach, the integral representations are found for the rectangular waveguide filled with three regions of dielectric. The boundary conditions in this case lead to two sets of five equations. Each set is solved simultaneously for the coefficients which specifies the dyadic Green's functions for this problem. Similarities to the previous results are discussed.

HIGH FREQUENCY TRANSMISSION SYSTEM FOR GYROTRONS

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University of Wisconsin-Madison, Madison, WI 53706-1691

Gyrotron is a powerful source of millimeter waves. Gyrotrons have lead to the development of transmission systems in overmoded wavewguides. Some aspects of this transmission system will be reviewed. Important parts of the transmission system are mode converters near the source as well as near the end of the transmission system. Details on the design and fabrication of these mode converters will be presented. New diagnostic devices have been developed for testing the operation of these mode converters. Details on three of the diagnostic devices will be included. Some of the problems that remain will be explained.

RESONANT MODES IN CYLINDRICAL CAVITIES LOADED WITH GYROTROPIC MEDIA

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D. Kajfez, Electrical Engineering Dept.
University of Mississippi, University, MS 38677

Finite Integration Technique (FIT) (T. Weiland, URSI Int. Symp. on EM Theory, 537-542, Budapest 1986) has been employed to formulate an algebraic eigenvalue problem whose eigenvalues are resonant mode frequencies for rotationally symmetric cavities inhomogeneously loaded with anisotropic and non-reciprocal (i.e. gyrotropic) media, such as microwave ferrite characterized by tensor permeability. Two different eigenvalue formulations result, one for the modes with no field variation with the angle of azimuth - modes with the modal index m=0, and one for the modes with sine/cosine field variation with the angle of azimuth ϕ - modes with m>0.

A mixed field formulation employing ϕ -directed electric and magnetic field components of m=0 modes, leads to a real quadratic eigenvalue problem. The eigenvalue problem shows that pure TE or TM modes can not exist in gyrotropic cavities, that is even the modes with m=0 are hybrid. Pure TE or TM modes can exist, however, in the case of "uniaxial" media, characterized by permittivity/permeability with zero off-diagonal tensor elements.

Magnetic field formulation has been employed for the m>0 modes in cavities with magnetic gyrotropy (tensor permeability), leading to a complex generalized eigenvalue problem. This formulation shows that the "degenerate" modes (R.F. Harrington, Time-Harmonic Electromagnetic Fields, 213-215, McGraw-Hill, 1961) can not exist in gyrotropic cavities.

The conclusion is that the abscence of pure TE/TM and the "degenerate" hybrid modes is caused, in the case of the magnetic gyrotropy, by the cross-coupling of magnetic field components perpendicular to the direction of the steady bias field. In the technically important case of axially magnetized ferrite, the coupling is between the ϕ -directed and r-directed magnetic field components.

MM-WAVE SOLID STATE TRAVELING WAVE AMPLIFIER

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It has in recent years been possible to construct monolithic mm-wave circuits on a chip. Currently various 3-5 semiconducting compounds in particular GaAs are used for this purpose. For the lower frequency ranges of a few GHz it is possible to use discrete components such as FET's, inductors, transformers and capacitors fabricated on the chip. At frequencies above few GHz connecting leads, capacitors and inductors have dimensions that are an appreciable portion of a wave-length. In this case on-chip transmission lines and discrete FET's are used to form the circuits. Distributed amplifiers using discrete high electron mobility transistors (HEMT) connected by on-chip strip lines have been reported.[1,2]

For higher frequencies it would be desirable to include the FET's in the transmission line. In this paper we present the design and analysis of a solid state traveling wave amplifiers (SSTWA) suitable for operation at mm-wave frequencies. The SSTWA consists of a large HEMT device incorpoarted in a double coplanner tranmsission line (DCTL). The device is several wavelengths long. The DCTL consists of five parallel metal lines. The first metal line is grounded and connected to the channel. It forms the source of the distributed HEMT. The next line forms a gate of the distributed HEMT and carries the double frequency pump voltage as well as a D.C. bias. The third metal line forms another gate which carries a D.C. bias and is A.C. grounded. It also acts as a shield between the two coplanar transmission lines. The fourth metal line is connected to the channel and forms the drain of the distributed HEMT. It carries the signal and a D.C. bias. The signal input is applied to one end of this line and the amplified output is obtained from the other end of the metal line. The last metal line is also connected to the channel. It carries a D.C. bias and is A.C. grounded. The portion of the channel between the fourth and the last metal lines forms a distributed load resistor.

The above mentioned distributed monolithic amplifier is expected to operate well above 20 GHz. In this paper we will present the theoretical analysis of this amplifier.

REFERENCES

1. "A 2-20 GHz, High Gain Monolithic HEMT Distributed Amplfier" by C. Nishimoto, R. LaRue, S. Bandy, M. Day, J. Eckstein, C. Webb, C. Yuen, and C. Zdasiuk, 1987 IEEE MTT-S International Microwave Symposium Digest Vol. 1 pp.155-159.

2. "A Low Noise Distributed Amplifier with Gain Control" by C. Hutchinson, and W. Kenna, 1987 IEEE MTT-S International Microwave Symposium Digest, Vol.1, pp. 165-168.

52-9 **CAD TRANSMISSION LINE MODEL FOR SLOW WAVE COPLANAR LINES WITH DIELECTRIC CAP LAYER AND THICKNESS METALLIZATION**

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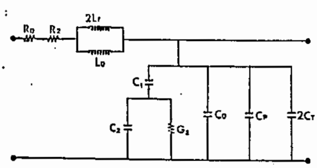
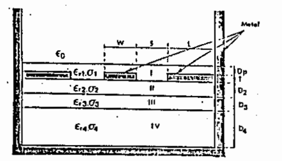
ABSTRACT

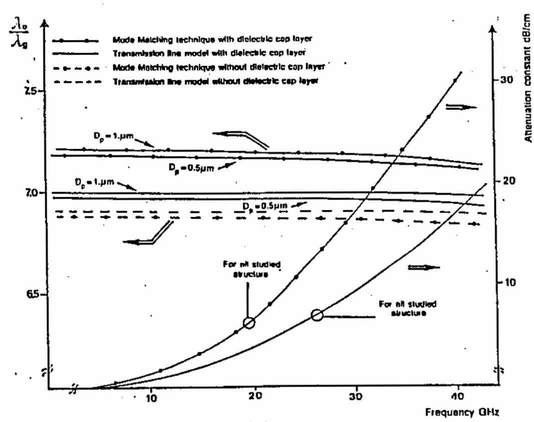
For CAD simulation, it is necessary to determine the frequency behaviour of coplanar lines laid on semiconductor substrates. Exact analysis can be performed by using numerical technics such as S.D.A. or Mode Matching. However such analysis can not be included in C.A.D. programs. For this purpose, we will present, at the Conference, an original model for coplanar lines laid on semiconductor substrate , which take into account both the influence of thickness metallization and dielectirc cap layer. The validity of our model has been tested by comparison with mode matching and S.D.A. results.



Associated transmission line model



Lossy studied structure with dielectric cap layer and thickness metallization



Evolution of a slow wave factor λ_0/λ_g and the attenuation versus frequency for the structure 1.b W=S=1.μm ; $\epsilon_{r2}=\epsilon_{r3}=\epsilon_{r4}=13$; $\sigma_2=\sigma_4=0.0$; $\sigma_3=205$ mho/cm ; T=0.1μm ; D2=0.1μm ; D3=0.2μm ; D4=100μm ; L=100μm

Wednesday PM

URSI-E Session 56

NOISE AND INTERFERENCE MODELING

Chairmen: J. R. Herman, A. Gupta, GTE

Room: Sheraton Comstock B *Time*: 3:15-5:00

SHOULD COMPUTER CLOCKS BE ALLOCATED?

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It is well known that computer clock signals and their harmonics cause much of the electromagnetic interference generated by modern computers (even those relatively low clock frequency personal computers).

As the frequencies of most computer clocks advance into the tens-of-megahertz range, and since these clocks are usually crystal controlled for technical reasons, an intriguing possibility exists for the mitigation of the effects of clock generated emissions.

If, for example, 10 MHz were standardized (regulated) as a basic clock frequency for small machines, most of the interfering harmonic signals would fall at harmonic frequencies, e.g., 20 MHz, 30 MHz, etc. (odd harmonics often predominate for such clock signals). Since the clock frequencies are crystal controlled, relatively small guard bands at the harmonic frequencies would suffice to limit interference with other services.

This approach might well be the basis for a new spectrum management tool.

FREQUENCY PLANNING FOR VHF FM BROADCASTING

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1612 Sofia, Bulgaria

Frequency planning is the most complicated task in transmitter networks (TN) planning. The frequency plan must fulfill the following basic requirements; (1) To guarantee interference-free work in TN; (2) To take into account all other radio services. Therefore, real frequency planning is preceded by an examination of the future electromagnetic environment. The results of such an analysis are usually presented as frequency-distance constraints (FDC). This approach makes possible the implementation of feasible heuristic algorithms (W.K.Hale, Proc. IEEE, Vol.68, No.12, pp.1497-1514, 1980) and leads to efficient spectrum utilization.

Assumptions:
(1) There is a cellular-type numeric relief map available, that allows terrain profiles acquisition.
(2) All transmitter stations (TS) characteristics, except the frequency, are known.

Definitions:
(1) Zone of coverage ZC (L,T,E) - a set of cells around a given TS, where the electromagnetic field strength (EFS) exceeds EdB in L% of locations for T% of time.

Main Issues:
(1) Zones of coverage determination: A sufficient number of uniformly distributed terrain profiles, originating in TS, are constructed. For a set of points along the profiles, the EFS value exceeded for T% of time is then calculated. In all cases, single frequency (for example, midfrequency in the band) and proper formulas have been used. Next step is determination of the EFS value, exceeded in L% of the examined points, situated in a given cell. Zone of coverage is the set of cells, where EFS exceeds an appropriate value.
(2) FDC determination: These zones of coverage for every pair of TSs are "mixed" together. In this way, zones of probable interference for all possible channel differences are produced. It is easy now, for every pair of TSs, to estimate the minimum frequency difference, providing an interference-free TN. These FDC will be referred to as in-band. The out-band FDC (due to other radio services) might be derived in the same fashion. This technique gives a higher quality FDC than recommended by CCIR (CCIR, Rec. and Rep., Vol.10, Part 1, pp.161-215, 1982).
(3) Frequency planning: A heuristic method with gradual frequency assignment is suggested. It is based on the idea of optimum integration of the interests of two sets: the set of TSs that have been assigned a channel and those still outstanding. The algorithm shows a better performance compared to other heuristics (T.O'Leary, EBU Review, No.207, pp.190-194, 1984).

ADAPTIVE MODELING OF MULTIPATH INTERFERENCE AND ITS SUPPRESSION

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Multipath interference is caused by propagation phenomena, which can be detrimental to the normal operations of communication systems. Some simple multipath cases may be predictable, but in most cases they cannot be predicted reliably due to complicated changing atmospheric and terrain conditions. This is especially true for the cases of mobile communications.

A predictable multipath interference may be reduced or eliminated through appropriate preventive measures, but in most cases they are impossible to predict reliably. As a result, they cannot be suppressed effectively.

This paper discusses an adaptive modeling technique of multipath interference channels and explains how such a technique may be used to suppress multipath interference. The advantage of this technique is that it can cope with multipath interference without the actual knowledge of the multipaths.

Detection of ELF Antenna Signals in Natural Background Noise for Antenna Pattern Measurements

Bradley Kangas, James C. Rogers

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Michigan Technological University
Houghton, Michigan 49931

Signal to noise ratio is a limiting factor in measuring the radiation pattern of a low powered ELF antenna. These measurements should be conducted tens to hundreds of kilometers from the antenna as a minimum and impulsive noise characteristics in this frequency range constitute a particular challenge to accurate determination of signal amplitude. Background noise data has been digitally recorded during the summer and fall in order to determine the probability density function (PDF) of the noise amplitudes and to facilitate development of an algorithm to process the antenna pattern measurement data in an optimum fashion.

Coherent detection of the transmitted signal provides the best means of estimating the transmitted signal strength. In order to reduce the uncertainty of the estimated signal it is desirable to average the received signal. However, there are clearly signal segments which are badly contaminated by impulsive ELF noise and which contaminate the signal estimation process. Selective inclusion of received signals is thus desirable.

The noise recorded are shown to possess a Beta type PDF for time segments 0.1 seconds in length. It is also shown that under the assumption of small signal to average noise (on the order of 0 dB or smaller SNR) there is an optimum level of allowable time segment energy. Time segments with energy above this level are excluded and those below are included in the signal estimation. It is shown that utilization of the noise PDF provides improvements in the signal above adjacent spectral noise by as much as 8.8 dB over that obtainable by simple coherent detection which does not use the noise statistics.

COMPUTER MODELLING AND TESTING OF NOISE

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U K .

Many branches of engineering and science require the computation and measurement of signals which contain both, the wanted information and noise. In the following a computer is used for the simulation of noise consisting of only a few sinusoidal waveforms and yet having the correct noise statistics. The model is then applied to a noise problem associated with mixers.

Narrow-band noise n(t) can be written in its narrow-band form $n(t)=r(t)\cos w_0 t + \theta(t)$ where r(t) and θ(t) vary in a random manner. Furthermore, r and θ are Rayleigh distributed and uniformly distributed respectively. For the sum of many closely spaced sinusoidal waves of spacing $\Delta f \ll B$ we have a Fourier series representation

$$n(t)=\sum_{\ell=-\infty}^{\infty} a_\ell \cos[(w_0+ l\Delta w)t +\theta]$$

The coefficients a_ℓ are large in the vicinity of the centre frequency, and small elsewhere. To simplify the considerable mathematical problems associated with the above equation the noise model has been modified such that all frequencies are fractional multiples of the centre frequency. Hence

$$n(t)=\sum_{r=n_1}^{n_2} a_\ell \cos (rw_0 t +\theta_r)$$

It will be shown that as few as five harmonically related sinusoids produce a reasonable facsimile of this noise. The same applies to the statistics of this model, e.g. its probability density and autocorrelation function.

In the following the noise model is applied to a single diode mixer in order to assess the effect of local oscillator noise on a mixer. The noisy pump drive can be expressed as

$$v_p = V_p \cos w_p t+\sum_{r=1}^{\infty} V_r \cos(w_r t+\eta_r)$$

Substitution of this waveform with the appropriate diode law permits calculation of the Fourier coefficients for a noisy oscillator and hence produces the noise corrupted diode waveform. Further mathematical manipulations result in expressions for conversion loss and noise figure.

Wednesday PM

URSI-B Session 58

EM THEORY III

Chairmen: R. D. Nevels, Texas A&M;
R. M. Bevensee, Lawrence Livermore Lab.

Room: Schine 304C *Time*: 1:25-5:00

A LOWERBOUND TO THE BROADBAND POWER SCATTERED FROM A LINEAR ANTENNA WITH A GENERAL LUMPED LOAD

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A general analysis has been made of the total "bistatic" power scattered from lossy, electrically linear bodies of arbitrary size and shape, excited by a single-frequency plane wave and loaded at one port. The load resistance at frequency ω under consideration is allowed to be negative, possibly from parametric operation of a nonlinear load. The following formula expresses a lowerbound to the broadband power scattered into a specified solid angle Ω:

$$(P_{sc})_{low} = \int |I^{s}_{sc}(\omega)|^{2}[r_s - |L|^{2}/4r_{rad}]\, d\omega \geq 0 , \qquad (1)$$

with the parameters defined as follows:

$I^{s}_{sc}(\omega)$ = current induced in the referenced shorted-load port by the incident plane wave at ω.

$|I^{s}_{sc}(\omega)|^{2} r_s$ = power scattered from the antenna into specified angle Ω with the referenced load port shorted.

L = complex crosspower coefficient over Ω between the "short-circuit "scatter" mode and ("open-circuit") "transmitter" mode defined at the referenced load port.

r_{rad} = radiation resistance of the "transmitter" mode into Ω, which accounts for surface losses and the net load losses at all ports other than the referenced one.

The straightforward proof of (1) will be presented.

REFERENCE

R. M. Bevensee, "Theorems About Maximum Radiation and Zero Scattering of the Linear Lossy Antenna", IEE Conf. Pub. 169, Antennas and Propagation, Part I: Antennas, pp 265-267, 1978.

CONVERGENCE AND ERROR ANALYSIS USING COLLECTIVELY COMPACT OPERATOR THEORY FOR RESISTIVE STRIP SCATTERING PROBLEMS

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Burnaby, B.C., V5A 1S6

Summary

The problem under consideration is that of determining numerically the surface current induced by an incident time-harmonic TM electromagnetic field in an infinite strip of positive resistivity, while providing some measure of the accuracy of the numerical solution.

The derivation of the surface current integral equation is outlined; the latter is shown to be a Fredholm integral equation of the second kind. Conditions are given under which the equation is uniquely solvable.

Writing the integral operator as a Steiltjes integral, discretizations of arbitrary order on variably-spaced points are given. These discretizations are shown to form collectively compact sets of operators. The bounds that are supplied by the theory of such sets of operators are written out explicitly. Furthermore, the condition numbers of the linear systems of equations are examined.

Finally, results of computer tests of the methods and bounds are reported.

Scattering and Diffraction
For Presentation in URSI Commission B

A SIMPLE FORMULA FOR TRANSVERSE MAGNETIC POLARIZATION QUASISTATIC BACKSCATTER FROM A RECTANGULAR RIDGE ON AN INFINITE GROUNDPLANE

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Northrop Corporation
Pico Rivera, California 90660

The problem class of interest is far-field backscatter of a plane wave from an infinitely long uniform ridge of perfect electric conductor (PEC) which lies on an infinite PEC groundplane. The direction of incidence is normal to the axis of the ridge and at an angle θ off normal to the groundplane, and the polarization is transverse magnetic, that is, with magnetic field parallel to the groundplane.

For wavelength λ sufficiently long compared to the cross-sectional dimensions of the ridge, this class of problems can be solved accurately by a combination of image techniques and standard quasistatic approximations. The general result has the simple form

$$\sigma_{KE} = (2\pi/\lambda)^4 \, 4A^2 \, (1 + C \sin^2 \theta)^2 .$$

Here σ_{KE} is the radar cross section (RCS) relative to a knife edge, that is, relative to the RCS for grazing incidence transverse electric polarization backscatter from a PEC halfplane; A is the cross-sectional area of the ridge; and the dimensionless parameter C, which depends only on the shape of the ridge, is a normalized measure of the electrostatic polarizability for the imaged ridge of area 2A when immersed in an electric field normal to the groundplane.

In this paper the method of moments solution of the relevant integral equation is used to determine C accurately for a rectangular ridge profile. It is then shown that the integral equation results for a ridge of height H and width W are matched accurately by

$$C = \{ 1 + [(\pi/2)(H/W)]^{1/p} \}^p ,$$

with $p = 1.29755$ (which gives $C = \pi$ when $H = W$). So long as the larger of H and W is still small compared to λ, this formula is valid for H/W from 0 to ∞. The results for these limiting cases are examined in detail.

The Determination of the Propagation Constant for the Travelling Wave in an Infinite Ground Plane

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Columbus, OH 43212

Abstract

The propagation constant for the travelling wave in a trough in an infinte ground plane is examined. The electromagnetic scattering from the infinite geometry is closely related to the finite extent geometries, which are common structures on aerodynamic bodies of interest. The travelling wave behavior is an essential element of the overall scattering from structures with joints that form troughs. The null field integral equation is used to determine the electromagnetic fields in the trough structure, and pulse basis functions are used to determine the distribution of the aperture fields. From this, the propagation constant is solved using the Newton-Raphson iterative scheme. Various geometries sizes are examined.

Measurements of two trough geometries are performed to validate the theoretical results. It is also shown that the technique can be suitably applied to characterize higher order travelling wave modes in a finite extent trough geometry.

2-D SURFACE INTEGRAL REPRESENTATION FOR HOMOGENEOUS ANISOTROPIC REGIONS

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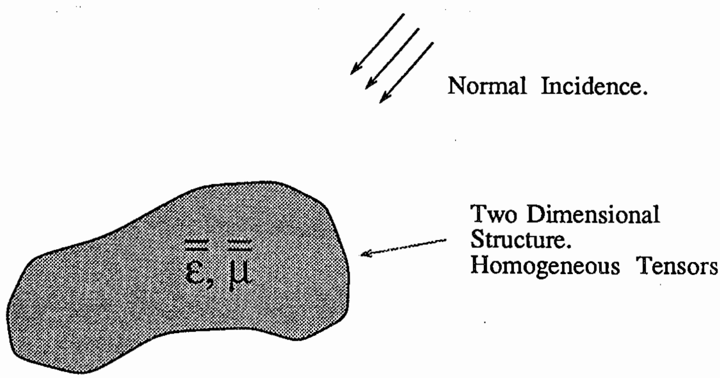
Damaskos, Inc. P.O. Box 469, Concordville, PA 19331

A mathematical statement of the Huygen's principle for an electromagnetic field in an anisotropic region is obtained by means of a mapping of the original region into a complex space via the material tensors $\bar{\bar{\varepsilon}}$ and $\bar{\bar{\mu}}$. In this two dimensional analysis, each polarization has a different representation and is therefore treated separately and via duality. An integral equation for the tangential field components is found and applied to some elementary scattering calculations which are discussed in detail.



THE LONGITUDINAL MAGNETIC POLARIZABILITIES OF SOME SMALL APERTURES

Noel A. McDonald
Royal Melbourne Institute of Technology
GPO Box 2476V, Melbourne 3001, Australia

Simple approximate expressions have been derived for the longitudinal magnetic polarizabilities of small apertures of four shapes: rectangle, diamond, rounded end slot, and ellipse.

For each shape the polarizability can be expressed in the form

$$P_m = f(\alpha)L^3$$

in which L is the aperture length and $f(\alpha)$ is a dimensionless function of the aperture width/length ratio α. It is shown that for all four shapes

$$f(\alpha) \to 0 \text{ as } \alpha \to 0$$
$$f'(\alpha) \to \infty \text{ as } \alpha \to 0$$

and for all shapes except the rounded end slot

$$f(\alpha) \to \text{constant times } \alpha \text{ as } \alpha \to \infty.$$

The selection of a suitable approximation function and curve fitting to numerical data gives

Rectangle: $$f(\alpha) = \frac{0.132}{\ell n(1 + \frac{0.660}{\alpha})}$$

Diamond: $$f(\alpha) = \frac{0.109}{\ell n(1 + \frac{2.33}{\alpha})}$$

Rounded end slot: $$f(\alpha) = \frac{0.187 + 0.052\alpha(1-\alpha)}{\ell n(1 + \frac{2.12}{\alpha})}$$

Ellipse: $$f(\alpha) = \frac{0.115}{\ell n(1 + \frac{1.00}{\alpha})}$$

The accuracy of these approximations is discussed.

The Mathematics of Marcuse's Power Loss Equation
Part I: Singularities of the Integrand

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Towson State University
Towson, Maryland

Robert H. Baran
U.S. Naval Surface Weapons Center
Silver Spring, Maryland

Members, IEEE

Summary: D. Marcuse has derived an equation for calculating the power lost by an electromagnetic wave travelling down a tapered dielectric rod. In the numerical integration of this equation, the first difficulty encountered is a ρ in the denominator of the integrand. Since the integration goes from -k to +k and $\rho=\sqrt{(k^2-\beta^2)}$, it follows that the integrand will have a singularity unless another ρ arises to cancel this one. Since we are using p^2 and q^2 all that is necessary is that p and q should be proportional to $\sqrt{\rho}$.

But examination of the integrand shows that p and q are not proportional to $\sqrt{\rho}$ but rather to ρ^{-2}. Now it is necessary to find a factor of $\rho^{-5/2}$. The missing factor is pursued thru all the equations until it is finally shown that the limiting values of the integrands near the end points of the interval of integration are in fact all zero.

[1] Marcuse, Dietrich: Radiation Losses of the Dominant Mode of a round Dielectric Waveguide. Bell System Technical Journal - October, 1970. pp1655ff

Mathematics of Marcuse's Power Loss Equation
Part II : The Inverse Square Law

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Mathematics Department
Towson State University

and

Albert D. Krall
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United States Naval Surface Weapons Center
White Oak,Silver Spring, Maryland

Members IEEE

Summary: Marcuse's power loss equation can be transformed into an integral of the Fourier type. Integration by parts followed by the Riemann - Lesbesgue lemma shows that the resulting integral when multiplied by the square of L will approach a non-zero constant. The value of this constant can be calculated by a numerical integration scheme.

When the results of that calculation are plotted on log-log paper along with the results of a more rigorous calculation it is seen that the power losses do indeed approach an inverse square law in the limit of large L.

Mathematics of Marcuse's Power Loss Equation
Part III: The Numerical Integration Scheme

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White Oak, Silver Spring, Maryland

Members, I.E.E.E.

Summary: In the course of implementing a numerical integration scheme, it became clear that the integrand had a sharp peak just below β=k , indicating that most of the radiation that emerges from the rod does so at a wave length close to the free space wavelength. But the integrand does go to zero at the end point of the interval of integration, so it is necessary to make the step size of the integration scheme sufficiently small so that the integrand will peak and start back down.

For antennas of moderate size, a Simpson's Law integration scheme is quite adequate. But, as the size of the antenna begins to get large, the results become increasingly erratic. This can be traced to the fact that the period of the integrand is getting smaller as L gets large. When the period gets so small that it is negligible compared to the step size of the integration scheme, then the values of the integrand become a more-or-less random sample of all the values taken on. To remedy this, an integration scheme due to van de Vooren and van Linde was used. It was devised for integrals of the Fourier type, but even this scheme had to be modified before it could be used.

The results of the calculations for selected rods are displayed and compared with the predictions of part II of this paper.

Wednesday PM

URSI-B Session 59

HIGH FREQUENCY SCATTERING BY DIELECTRIC BODIES

Chairmen: P. H. Pathak, Ohio State University;
R. Tiberio, Univ. of Florence

Room: Newhouse A1 *Time*: 1:25-5:00

1:30	**On The Relation Between Green's Functions for Open and Closed Cylindrical Dielectric Layers** K. Arichandran, N. Subramaniam, University of Malaya; L. B. Felsen, Polytechnic University	266
1:50	**Scattering of a Plane Wave from a Coated Circular Cylinder at Oblique Incidence- GTD Solution** S. Kato, N. Wang, The Ohio State University ElectroScience Lab	267
2:10	**Diffraction of a Plane Wave by a Rectangular Dielectric Rod** K. Kobayashi, University of Wisconsin-Madison; T. Inoue, Tokyo Electric Power Company, Inc.	268
2:30	**Resonances Of An Impedance Strip** J. D. Kotulski, Sandia National Laboratories	269
2:50	**COFFEE BREAK**	
3:20	**Diffraction by a Magnetic Dielectric Half-Plane Using Generalized Impedance/Resistive Boundary Conditions** R. G. Rojas, L. M. Chou, P. H. Pathak, The Ohio State University ElectroScience Lab.	270
3:40	**Equivalent Edge Currents For An Impedance Wedge** G. Pelosi, S. Maci, G. Manara, R. Tiberio, University of Florence; A. Michaeli, Armament Development Authority, Israel	271
4:00	**Intrinsic Modes In A Wedge-Shaped Taper Above Anisotropic Substrates** I. T. Lu, Polytechnic University	272
4:20	**Quasi-Optics of a Thin Film Polarization Converter** M. A. Sletten, S. R. Seshardi, University of Wisconsin-Madison	273
4:40	**Quasi-Optics of the Evanescent Wave Excitation of Planar Dielectric Waveguides** Z. H. Wang, University of Illinois at Urbana-Champaign; S. R. Seshadri, University of Wisconsin-Madison	274

ON THE RELATION BETWEEN GREEN'S FUNCTIONS FOR OPEN AND CLOSED CYLINDRICAL DIELECTRIC LAYERS

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Department of Electrical Engineering
University of Malaya, Pantal Valley
Kuala Lumpur, Malaysia

and

L.B. Felsen*
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Weber Research Institute
Polytechnic University, Farmingdale, New York 11735 USA

Real ray and complex ray (Gaussian beam) techniques furnish powerful building blocks for tracking high frequency wave fields through curved layered environments. Being asymptotic in nature, the accuracy of these constituent ray field representations in various parameter ranges must be assessed by comparison with rigorous reference solutions for canonical structures. A cylindrically curved shell is canonical but its Green's function representation in terms of generalized ray integrals, whose asymptotic approximation yields the geometrical ray fields, is based on spectral decomposition in the azimuthal coordinate ϕ. By superposition of these spectral integrals, which span an infinite ϕ domain, one may synthesize the azimuthally periodic and nonperiodic Green's functions for a closed ($0 \leq \phi \leq 2\pi$) and "open" ($-\infty < \phi < \infty$) shell, respectively. The generalized ray integrals involve the order of the cylinder functions as integration variables and are not easily computable. On the other hand, for source locations inside (but not very close to) a closed shell of moderate radial extent, the conventional angular harmonic series expansion poses no computational difficulties. Rearranging this Green's function and applying Poisson summation to appropriate portions is shown to generate a harmonic series representation for the group of ray integrals that describes a specified number N of reflections at the inner boundary of the shell before the ray passes through the shell into the exterior. Computations based on this reference solution permit testing of geometrical ray field calculations for the same reflection index N. Comparisons are presented and discussed for various combinations of parameters. Special attention is given to a local plane parallel slab approximation of the curved layer, which is of interest for radome applications where the field from the source passes directly through the shell (N=0 case).

SCATTERING OF A PLANE WAVE FROM A COATED CIRCULAR CYLINDER AT OBLIQUE INCIDENCE— GTD SOLUTION [1]

Stephen Kato and Nan Wang*

The Ohio State University ElectroScience Lab
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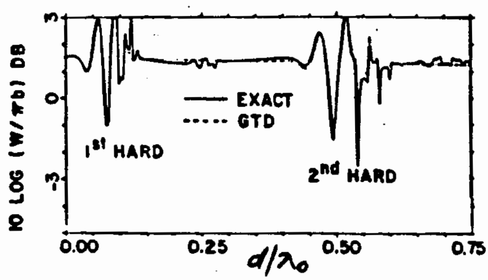
Columbus, Ohio 43212

The high frequency scattering by a coated circular cylinder due to an obliquely-incident plane wave has been investigated. Using the physical-optics approximation for the surface fields on the dielectric/air interface, the geometric-optics (GO) fields for the scattering from the coated cylinder have been obtained. It is shown that in terms of the ray-fixed coordinate system, the usual, simple ray format employed for the perfectly-conducting surface remains unchanged for the coated conducting surface. For the coated surface, one has to employ the reflection coefficients for a planar grounded slab illuminated by a plane wave.

A creeping wave (residue series) solution for the scattered fields in the shadow region was also obtained. Unlike the normal incidence case, one coupled transcendental equation was obtained for the creeping waves associated with the coated cylinder. The significance of the couplings between the TE and TM components will be discussed. As an illustrative numerical example, the normalized scattering width for an infinitely long coated circular cylinder for oblique incidence in the plane of incidence is shown in the following figure. The explanations for the four distinctive groups of ripples will be discussed in the paper. Other examples are also included in the paper.



Normalized scattering width for an infinitely long coated circular cylinder for oblique incidence (θ_i=45°) in the plane of incidence, TE case (E_ϕ). $ka=35$, $\epsilon_r=2.54$

[1] Work supported in part by Department of Navy, Joint Service Electronics Program Contract N00014-78-C-0049 with the Ohio State University Research Foundation.

DIFFRACTION OF A PLANE WAVE BY A RECTANGULAR DIELECTRIC ROD

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This paper presents a rigorous solution to the problem of diffraction of an E-polarized plane electromagnetic wave by a rectangular dielectric rod. The method of formulation is based on the Wiener-Hopf technique and is similar to that used by the first-named author to analyze the diffraction by a rectangular conducting rod (Bull. Fac. Sci. Eng., Chuo Univ., 25, 229-261, 1982). Although some aspects of this problem have previously been treated by Uchida et al. (Trans. IECE Japan, J65-B, 1417-1424, 1982) with the aid of the similar technique, the solution presented here is entirely different. It should be emphasized that the solution obtained by Uchida et al. is applicable only for lossy dielectrics, whereas our solution is valid in principle even when the dielectric medium has no loss.

Introducing the Fourier transform pair for the unknown scattered field and applying the boundary conditions in the transform domain, this problem is formulated in terms of the simultaneous Wiener-Hopf equations satisfied by six unknown spectral functions. The Wiener-Hopf equations are then solved exactly via a factorization and decomposition procedure. However, the solution thus obtained is formal in the sense that several kinds of branch-cut integrals involving unknown functions and infinite number of unknowns are contained in the final solution. By employing a rigorous asymptotics with the aid of the edge condition, the approximate solution in the transform domain is derived. Furthermore, the scattered far field in real space is evaluated asymptotically by taking the Fourier inverse and applying the saddle point method. We have carried out some numerical computations for the far field pattern based on the above procedures and investigated the characteristics of the scattered field. Comparison has also been made with the results by Uchida et al. and some discrepancies have been recognized.

RESONANCES OF AN IMPEDANCE STRIP

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The relationship between the high-frequency ray fields and the resonances of scatterers has been exposed by a number of investigators. Using these relationships the resonances of an impedance strip are determined by the use of the geometrical theory of diffraction. In the context of GTD the ray fields are tracked through the multiple interactions of the edges of the strip and then are appropriately summed to yield the resonances of the impedance strip. The resonances are determined for different types of coatings. The limiting case of the perfectly conducting strip is compared to previously derived results.

DIFFRACTION BY A MAGNETIC DIELECTRIC HALF-PLANE USING GENERALIZED IMPEDANCE/RESISTIVE BOUNDARY CONDITIONS

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Generalized Impedance boundary conditions are derived for a planar, homogeneous, magnetic dielectric slab grounded by a planar perfect electric/magnetic conductor. The corresponding Generalized Resistive boundary conditions for a slab in free-space are also developed from the Generalized Impedance boundary conditions. These boundary conditions are then used to obtain uniform asymptotic high frequency ray solutions for the diffraction of an obliquely incident plane wave by a magnetic dielectric half-plane which is in free-space or when it is grounded by a planar perfect electric/magnetic conductor.

It is important to emphasize that unlike most solutions found in the literature, the boundary conditions developed here recover the **exact** geometrical optics fields as well as the **exact** propagation and attenuation constants of the surface wave fields. Furthermore, it is shown that the boundary conditions given here reduce to those given previously by [Weinstein, The Theory of Diffraction and the Factorization Method, The Golem Press, 1969] for the limiting case of a very thin half-plane. Likewise, the solutions given here recover those based on Weinstein's boundary conditions in this limiting case.

The half-plane solutions presented here are shown to be very accurate by comparing them with those obtained by an independent approach based on the moment method. The half-plane solutions are also used to obtain the solution for the scattering by a magnetic dielectric strip of an obliquely incident plane wave. This solution is also shown to be very accurate by comparing it with the corresponding moment method solution.

EQUIVALENT EDGE CURRENTS FOR AN IMPEDANCE WEDGE

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University of Florence, Italy
and
A. Michaeli
Dept. 87, Armament Development Authority, Israel

In many applications the high-frequency description of the field scattered by a wedge for arbitrary directions of illumination and observation is useful. In particular, in calculating the RCS of complex targets it is very important to cover those directions which can not be predicted by the ray technique of the GTD, i.e. not on the Keller cone of diffraction. It has been shown that this goal can be achieved on a rigorous basis by the method of equivalent edge currents (MEC). To this end, suitable expressions were derived for a local perfectly conducting wedge (A. Michaeli, IEEE AP, 3, 1984; 7,8, 1986).

Due to the practical importance of non-perfectly conducting materials, this method has been now extended to treat the case of a wedge with surface impedance boundary conditions. In this paper, explicit expressions for the pertinent equivalent edge currents are presented. The derivation is based on the asymptotic relationship between the surface radiation integral of the PTD and the line radiation integral of the MEC. The resulting expressions are deduced from those exact solutions of the canonical impedance wedge problems that are available for skew incidence. These solutions were obtained for an exterior $n\pi$ wedge angle, with $n = 1,2,3/2$, by applying the Maliuzhinets' technique (T.B.A. Senior, Radio Sci, 2, 1986; R. Rojas, IEEE AP, 1988).

For an impedance wedge both electric and magnetic currents are involved in the radiation integral, which is evaluated over the ray coordinate by an asymptotic endpoint approximation. Thus, explicit high-frequency expressions for equivalent edge currents are given in terms of PO and fringe components. A convenient matrix formulation is adopted which is useful for both its physical interpretation and numerical calculations.

INTRINSIC MODES IN A WEDGE-SHAPED TAPER ABOVE ANIIOTROPIC SUBSTRATES

I.T. LU

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Intrinsic modes yield exact solutions away from the tip in a wedge-shaped taper with penetrable boundaries (J. M. Arnold and L. B. Felsen, J. Acoust. Soc. Am., 76, 850-860, 1984). Unlike adiabatic modes, they are uncoupled and pass smoothly through the cutoff transition. The model has been generalized to accommodate stratified multi-wave substrates (I.T. Lu and L.B. Felsen, Proceedings of the Conference on Ocean Seismo-Acoustics, edited by T. Ajak and M. Berkson, Plenum Press, New York, 1986) and weekly range-dependent environments (I.T. Lu and L.B. Felsen, J. Acoust. Soc. Am., 81, 897-911, 1987). Here, a wedge-shaped taper above anisotropic substrates is considered. In the spectral representation of intrinsic modes, the plane wave reflection coefficient from the substrate depends on the orientation of the optic axis, which, in turn, affects the cut off condition. Since the phase propagation vector and average power flow vector are usually non-parallel in anisotropic media, the field in the substrate will be substantially different from that in isotropic cases.

QUASI-OPTICS OF A THIN FILM POLARIZATION CONVERTER

Mark A. Sletten and S. R. Seshadri*
Department of Electrical and Computer Engineering
University of Wisconsin-Madison, Madison, WI 53706-1691

A planar thin isotropic film sandwiched between an isotropic cover and an electro-optic crystal (substrate) which is uniaxially anisotropic can support transverse electric and transverse magnetic guided modes. When an external electric field is applied to the substrate and is harmonically modulated in the propagation direction to provide the necessary phase matching, the two modes coherently interact and exchange energy in the propagation direction. The governing equations of this interaction are deduced from a quasi-optic theory, and are analyzed to yield the requirement for the complete polarization conversion. Two different orientations of the crystal are considered and representative numerical results are provided to illustrate the operation of the polarization converter.

QUASI-OPTICS OF THE EVANESCENT WAVE EXCITATION OF PLANAR DIELECTRIC WAVEGUIDES

Zi Hua Wang[1] and S. R. Seshadri[2*]
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University of Illinois at Urbana-Champaign, Urbana, IL 61801
[2]Department of Electrical and Computer Engineering
University of Wisconsin-Madison, Madison, WI 53706-1691

The governing equations for the evanescent wave excitation of the guided mode in a planar dielectric waveguide are derived using a quasi-optical technique. The coupling between the prism dielectric and the film waveguide is assumed to be weak. The factor by which the field decays from the surface of the film waveguide to the surface of the prism dielectric is chosen to be the small parameter for ordering the various field quantities. Even though the power in the incident wave is larger than that in the guided mode, the guided mode amplitudes defined at the film surfaces are assumed to be of the order of unity, and the incident-, the reflected-, and the transmitted-wave amplitudes defined at the surface of the prism dielectric are assumed to be weaker by one order in the small parameter. Justification is provided for this type of ordering of the field amplitudes.

The governing equations are in their canonical form, and they are consistent with the requirements of reciprocity and power conservation. Few important results obtained from the solution of the governing equations are summarized.

Wednesday PM

URSI-B Session 61

NUMERICAL METHODS FOR ANTENNAS

Chairmen: K. K. Mei, U.C., Berkeley; J. Kauffman, North Carolina State

Room: Newhouse 254 *Time*: 1:25-5:00

COMPARISON OF EQUIVALENT CIRCUIT MODEL AND INTEGRAL EQUATION FORMULATION OF FSS WITH I-BAR ELEMENTS

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In this paper, a frequency selective surface(FSS) consisting of periodic I-bar patch/aperture elements is studied via both the equivalent circuit model(ECM) and the integral equation formulation (IEF). The I-bar patch element FSS exhibits band-rejection characteristics at its first resonant frequency; whereas, the aperture element FSS exhibits band-pass characteristics.

For a vanishingly thin sheet FSS with periodic I-bar patch elements, a simple LC equivalent circuit model may be derived from the quasi-static approximation of (Marcuvitz, Waveguide Handbook,280-284,1951). With this model, the transmission and reflection characteristics of the FSS is calculated as a wave propagating along a transmission line with a shunt admittance representing the FSS. This approach provides an efficient evaluation of the FSS's characteristics. Also, the Babinet principle may be implemented to determine the aperture element FSS's characteristics.

Usually the ECM approach is less accurate at oblique incidence and is incapable of evaluating the crosspolarization characteristics. To overcome these deficiencies, two IEF approaches are developed. First, for the thin-sheet I-bar patch element FSS, the IEF method similar to (Montgomery, IEEE TAP,23,70-75,1975) is employed to determine the unknown currents on the I-bar elements and the scattered fields. The second IEF approach treats the I-bar aperture element in a thick screen as a ridge waveguide element and the complete eigenvalue solution is found as in (Montgomery, IEEE MTT,19,547-555,1971). The unknown aperture fields and the scattered fields are then found via solving the IEF derived from the mode-matching technique.

Sample calculated results will be given to compare with the measured data to determine the accuracy, limitations and advantages of each method.

A CONTRIBUTION TO THE ANALYSIS OF THE BROADWALL SLOT ANTENNA

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Raytheon Company
Missile Systems Division
Bedford, Ma 01730

Antennas consisting of multiple slots in the broadwall of rectangular waveguide are widely used in applications where light weight and shallow depths are important. Although analyses of such structures have been and continue to be of great interest these antennas are usually designed empirically because accurate solutions have simply not been available. This paper presents the results of a Galerkin type moment method approach to the multiple slot antenna. The method used is similar to the single slot analysis of Lyon and Sangster (IEE Proc., Vol. 128, Part H, No. 4, Aug 1981) but is generalized to include the vector nature of the arbitrary width slot solution as well as the mutual coupling between slots. The equivalence principle is used to isolate the three regions characterizing the problem, the interior (waveguide) region, the slot region, and the exterior (free space) region. Magnetic currents are placed over the shorted apertures to restore the fields in the various regions and the boundary conditions on tangential electric and magnetic fields couple the regions back together. This formulation includes in a natural way the mutual coupling between the slots both externally and internally. The thickness of the waveguide wall is included and an arbitrary (finite) number of slots can be analyzed, but the emphasis here is on the two slot problem. Entire domain functions are used as expansion and testing functions for numerical efficiency. Although the present work can address longitudinal or transverse slots of arbitrary aspect ratio the analysis can be extended to the rotated slot problem through a simple, although tedious, transformation of coordinates. Comparisons to published results are made which verify the accuracy of the individual components of the admittance matrices as well as the solutions for the single slot field distributions.

APPLICATION OF NUMERICALLY GENERATED, BODY-FITTED, CURVILINEAR COORDINATE SYSTEMS TO ELECTROMAGNETIC SCATTERING PROBLEMS

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HAWTHORNE, CALIFORNIA 90250

The finite-difference approach based on the generalized scattering amplitude concept (R. T. Ling, AIAA Journal 25, 560-566, 1987) is applied to the scattering of electromagnetic waves by a perfectly conducting two-dimensional airfoil. The transformed Helmholtz equation and associated boundary conditions in terms of the generalized scattering amplitude are solved in a numerically generated, body-fitted, curvilinear coordinate system obtained by grid generation procedures commonly used for airfoil aerodynamic computations. Numerical results are obtained for normal incidence of electromagnetic waves on a modified NACA 4418 airfoil with a chord length approximately equal to the wavelength of incident waves. Bistatic scattering cross sections and induced surface current for both E- and H-polarizations will be presented. The results of the finite-difference method are in excellent agreement with those obtained by the method of moments.

It is interesting to note that for a 3-D electromagnetic scattering problem, the use of body-fitted, curvilinear coordinate systems not only simplifies the enforcement of surface boundary conditions but also allows it to be reduced to two independent scalar scattering problems (R. T. Ling, AIAA paper 87-0487). To achieve this reduction, it is necessary to formulate the electromagnetic scattering problem in terms of a pair of scalar Debye potentials which satisfy the scalar Helmholtz equation and from which the electric and magnetic field vectors can be generated. When a body-fitted coordinate system is used, the media interface conditions for the two Debye potentials are uncoupled from each other so that they can be solved independently.

CALCULATION OF THE ELECTROMAGNETIC FIELD AT EDGES WITH THE MMP-METHOD

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Swiss Federal Institute of Technology, Zurich, Switzerland
G.Klaus, *Amstein and Walthert electrical consulting engineers*

The knowledge of the singular behaviour of the electromagnetic field in the direct neighbourhood of an edge has been and remains an important matter, especially for scattering and high voltage problems.

In the past a few special cases were solved with the help of analytical methods. On the other hand, thanks to better computers and more powerfull algorithms, we have now numerical methods, which give excellent solutions in more realistic geometrical configurations. The remaining question consists in checking the reliability of the results obtained by our general numerical method for these special cases.

All the fields calculated with the MMP-method are finite. Hence, it includes implicitly both the Meixner edge condition and the Sommerfeld radiation condition. We will show that our MMP-method can solve the edge problems in a quite accurate and satisfactory way.

A cone on top of a cylinder exposed to an incident plan wave, will be our exemple of a fully dynamic 3-D problem with rotational symmetry.The results will be presented for perfectly conducting as well as for lossy materials.

THE NEAR- AND FARFIELD-SIMULATION OF RADIOS HELD BY MAN CALCULATED WITH THE MMP-METHOD.

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Swiss Federal Institute of Technology, 8092 Zurich
Quirino Balzano, Motorola, Inc., Ft. Lauderdale

The market of the widely used two-way portable communication equipment is growing quickly. The public concern about biological effects of electromagnetic fields forces the producer to optimize the antennas to limit losses inside the body of users. On the other hand, scientists who investigate the interaction between EMF and biological systems are interested in the field distribution inside the body. This paper has been motivated by the relation of these considerations.

There are three major difficulties for the nummerical methods used to model a radio handheld by a human. Besides the fact that it is a real 3-dimensional problem, the distance between source and man is well below a wavelength. Therefore the scattering object is in the close nearfield, where the gradients of the field components are very high. The simulation of the antenna itself is a problem, especially the feedpoint, which in fact is a model junction between a 2-dimensional structure (line) and a 3-dimensional problem (antenna).

The Multiple MultiPole (MMP) Method which was first proposed by Hafner (Diss ETH Nr. 6683) has major advantages for this kind of problem compared to other numerical methods like Finite Element (FE), Finite Difference (FD) and Method of Moments (MM). One advantage is that the basis functions are analytical expansions of the Maxwell equations (in contrast to FE- and FD-method) and are not expanded on the boundary (in contrast to MM). Only the boundary conditions are numerically approximated. These features reduce considerably the problems of the strong non-uniform field around the antenna with high accuracy even on the boundary. The matrix, that has to be solved, is small and compact.

The human model that we used is axissymmetric, homogenous (soft muscle tissue) and it has a head-body-leg shape. The model of the portable radio is a dipol-like antenna made of perfect conductors.

The results are compared with the measurements of the radiation patterns, feedpoint impedance and RF absorption in the head of the user made previously. The agreement between experimental and numerical values will be discussed.

IEEE AP-S /URSI Symposium
Syracuse,New York
June 6-10 ,1988

Suggested topics : Scattering and diffraction/ Numerical methods

Efficient iterative preconditioned Krylov methods for solving the 3-D Maxwell equations and related scattering problems in Aerospace Engineering.

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AMD/BA Industries , DEA, Aerodynamic Department
78 Quai Marcel Dassault ,92214 Saint-Cloud ,France

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The numerical simulation of the Maxwell equations has been the subject of quite intensive efforts these last ten years .Such efforts are directly related to the necessity of a deep understanding of electromagnetic wave propagation in perfectly and non perfectly conducting medium arising in the design of aircrafts via Radar Cross Section minimization.

Due to the strong interest in high frequencies (>= 1Ghz), the monochromatic discretization of the Maxwell equations leads to very large systems of linear equations in finite dimension which require efficient solutions; fortunately during the same decade ,the scientific community has seen the emergence of supercomputers allowing the simulation of these wave propagation problems which can be particularly complicated when phenomena such as non linear interactions of anisotropic materials occur.

In order to handle the highly complicated geometries associated to aerospace applications , triangular finite element moment methods have been preferred by some schools (S.M.Rao,Appli. of the M.M to Elec. Scatter.,Rochester Inst. of Tech.,1984) since they allow the use of non structured meshes with local self adaptive mesh refinement .

Starting from the integral equations (R. Mittra,Comp. Tech. for Elec, chap.4,159-264,1973) and the associated linear Galerkin moment method with the surface electric current as unknown variable,the goal of this paper is to discuss selected iterative methods for solving those large dense ,complex and indefinite linear systems resulting from the triangular discretization of a perfectly conducting surface .

An important part of our lecture will be devoted to the discussion of efficient iterative Maxwell solvers including biconjugate gradient(D.A.H. Jacob,IMA Jour. of Num.Anal.,6,447-452,1986) ,conjugate gradient squared (E.F.Kaasschieter,Report 86-21,Dept of Math and Infs,Delft Univ.of Tech.,1986) and Krylov methods -better known as GMRES (P.Brown and Y.Saad ,Siam Jour.on Scien.and Stat. Comp.,1987) -and the comparison with direct ones whose factorisation may not fit into the computer core and take too much computing time .As the hermitian part of the system is not positive definite ,all the above conjugate gradient type methods do require appropriate preconditionners because if not the associated algorithms are definitely too slow. . Alternative ways of preconditoning will be considered such as diagonal scaling , preconditioning sparse operators obtained by deleting small elements of the incomplete factorized matrix (R.Glowinski ,J.Périaux,O.Pironneau, An efficient precond. scheme for iter.sol. of PDE, Appl.Math. Model.,1980,Vol 4) or hierarchical multilevel techniques (R.Bank and Y.Yserentant,Berlin,1987)

Numerical experiments on 3-D test problems , some of them of industrial interest ,will illustrate in terms of CPU and main storage savings, as compared with direct factorization ,the possibilities of the above methods. Further extension to arc-lengh continuation methods using the frequency as the continuation parameter will be also considered.

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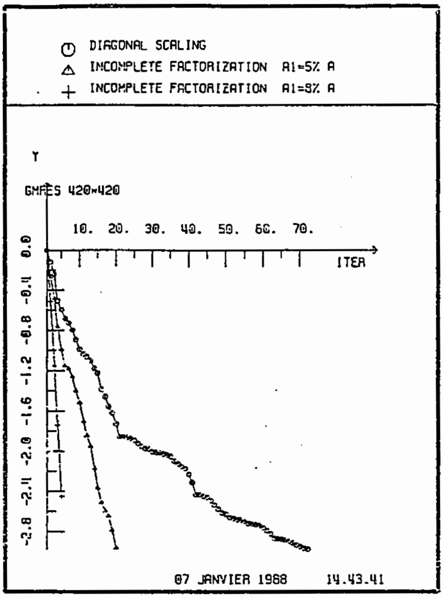
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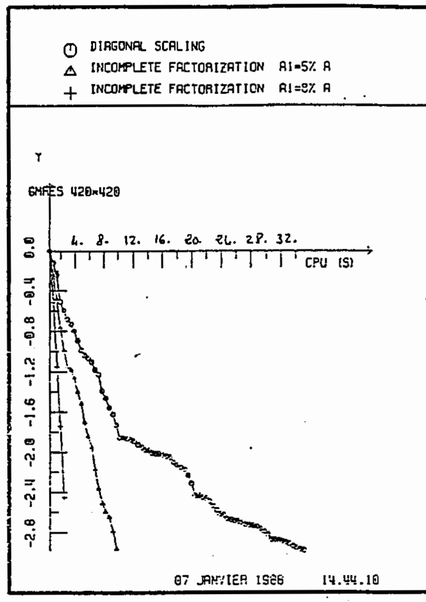
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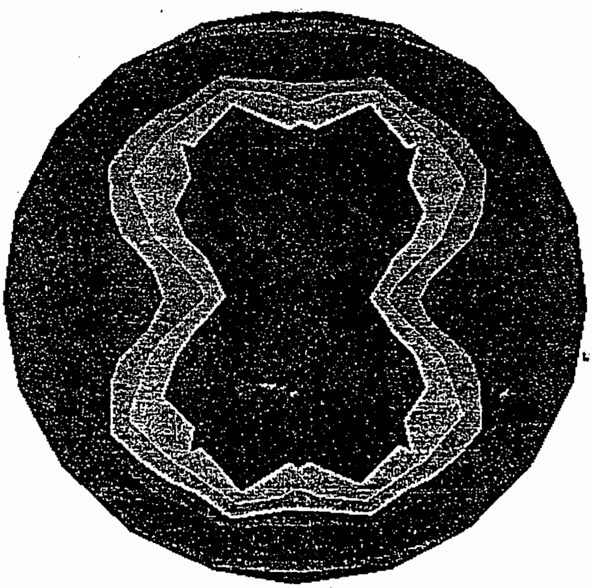

ASPECTS OF CONVERGENCE IN THE SPECTRAL DOMAIN FORMULATION OF EM PROBLEMS

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Raj Mittra
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The spectral domain formulation is used in a variety of electromagnetic problem formulations. For example, consider planar geometries of infinte and finite extent, such as Frequency Selective Surfaces (FSS's), microstrip and finline. The spatial representation of the fields then involves summations with an infinite number of spectral terms or integrals with infinite support. Likewise, the inner products formed in the spectral domain for a Method of Moments (MoM) solution involve such operations. Issues related to the asymptotic forms and particularly convergence are therefore of the utmost importance in order to achieve satisfactory results with minimal, or perhaps realistic, computational effort.

Numerical data for shielded microstrip and infinite FSS geometries illustrate the sensitivity of the particular result to the number of spectral terms and the number and form of the basis functions used in a MoM solution. The Relative Convergence phenomena and the relationship of the condition number of the system of equations which are solved for the unknowns are noteworthy issues.

General conclusions on the subject of numerical convergence when using the spectral domain formulation can be drawn. Such conclusions are important when tackling the finite FSS and microstrip discontinuity problems.

GENERATION OF WIDEBAND DATA FROM THE METHOD OF MOMENTS BY INTERPOLATING THE IMPEDANCE MATRIX

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Columbus, Ohio 43212

This paper describes a technique for reducing the computer CPU time in performing a method of moments (MM) computation over a broad frequency range. A frequency sweep of typical antenna parameters, such as input impedance or radar cross-section, normally consists of a number of peaks and minimums caused by resonance effects or by addition and cancellation of fields. In order to reliably duplicate such a curve one must make computations at relatively small intervals in frequency. Since in a MM computation it is necessary to evaluate a new impedance matrix at each new frequency, the CPU time to perform a MM computation over a wide bandwidth can be prohibitive.

The impedance matrix interpolation scheme is based upon the fact the the elements in the MM impedance matrix are often relatively slowly varying functions of frequency. As a result, it is possible to evaluate the MM impedance matrix at a few widely spaced frequencies, and then interpolate these stored matrices to obtain the impedance matrix at intermediate frequencies. Further, it is found that the frequency interval for computation of the impedance matrix can be significantly increased if one incorporates simple properties of the frequency dependence of the elements in the impedance matrix into the interpolation scheme.

Numerical results are shown for the frequency dependence of the input impedance of a dipole and the radar cross-section of a plate. In particular it is shown that the dipole input impedance can be evaluated with reasonable accuracy over a 7 to 1 bandwidth with only three evaluations of the MM impedance matrix.

A TECHNIQUE FOR IMPROVING THE ASYMPTOTIC SOLUTIONS FOR POLYGONAL PLATES BY USING THEM AS BASIS FUNCTIONS IN THE CONTEXT OF MOM

Albert Chang and Raj Mittra*
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The use of trigonometric type of entire domain basis functions has been explored by several researchers in the past with a view to reducing the matrix size in the Method of Moments approach. While such entire domain basis functions have been successfully employed to solve a variety of scattering problems, it has been noted that the resulting impedance matrices typically have high condition numbers, and that the solution becomes susceptible to large errors if the number of the basis functions is increased beyond a certain limit.

In a previous paper [1], the authors have investigated the use of Gaussian type entire domain basis functions to obtain a well-conditioned impedance matrix with a typical reduction in the matrix size by a factor of two-to-three over those generated by using the subdomain functions. However, even with the Gaussian basis functions, the matrix can become unmanageably large for large scatterers, and it becomes necessary to devise alternate schemes for handling such problems. In this paper, we present one such scheme to solve the problem of thin plates of polygonal shape that can be large compared to the wavelength. We show how the exact solutions for the current distribution on a perfectly conducting half-plane can be used to solve a variety of plate problems, either directly or as entire domain basis functions in a hybrid moment method. The advantage of the hybrid moment method over the conventional subdomain approach is that it requires a substantially smaller matrix size for comparable accuracy, and yet, does not suffer from the instability problems associated with the trigonometric entire domain functions.

Although MoM is typically limited by the associated matrix size, it does enjoy an important salutary feature that it takes into account all the possible interactions from different parts of a scatterer; hence, it is numerically rigorous. In contrast, high frequency asymptotic methods , e.g., the GTD, are limited in their applications to situations where the scattering is a localized phenomenon, and where the diffraction coefficients for the canonical problems associated with the geometry under consideration are available in a form convenient for numerical computation. Thus, if the scatterer supports a traveling wave, and, consequently, different parts of the scatterer actively interact with one another, the scattering phenomenon is no longer local and the use of GTD-type algorithms is known to introduce significant errors for certain aspect angles. Likewise, if the structure contains a corner-type geometry, for which the diffraction coefficient is not yet available, GTD-type approaches become inaccurate when the tip-diffraction is ignored. To obviate these problems associated with the pure asymptotic methods, we have developed a hybrid technique by combining MoM with the half-plane solution that is easily calculated. The gist of the hybrid method is that it employs the half-plane solutions as entire domain basis functions, whose functional forms are chosen on the basis of the physics of the problem, viz., the phenomenon of edge diffraction. Combining these entire domain functions with the subdomain ones allows one to incorporate the contributions from the corners, as well as the multiple diffractions from the edges, and still construct an accurate solution of large plate problems using only a moderate size matrix. Although hybrid approaches have been suggested in the past to treat PEC scatterers [2], there is an important difference in the way the entire domain basis functions are chosen in the present scheme that enables one to use them for all angles of incidence, including those near grazing. Furthermore, the method is well-suited for handling resistively-loaded plates, which have not been discussed in the context of the hybrid approach.

Let us turn now to the numerical results. The inset in Fig 1 shows the geometry of a square plate, which was treated solely by using an appropriate combination of the exact solutions for the PEC half-plane problem. Thus the use of subdomain functions was entirely bypassed and, hence, no matrix inversion was required. Figs. 1 and 2 show the monostatic RCS of PEC square plates of two different sizes, viz., 5.078 λ square and 3.906 λ square, respectively. Good agreement between the calculated and measured results is apparent from these figures. Next, we consider the problem of scattering from a PEC triangular plate, whose geometry is shown in Fig. 3, together with the plots of computed and measured monostatic RCS for the plate. For this case, it becomes necessary to utilize a combination of subdomain basis functions and entire domain functions based on the half-plane currents, in the context of MoM, in order to generate an improved solution. This can be seen from Fig. 3, where we present the results obtained by utilizing only the half-plane solutions. We note that while these results are comparable in accuracy to those derived by using the UTD or the Equivalent edge current approach, they deviate substantially from the measured data in a wide angular range. Figure 4 shows that the "half-plane currents only" results can be substantially improved by using these as entire domain basis functions and combining them with the subdomain functions. The improvement is particularly noticeable in the angular range of 120 to 180 degrees. And yet, the matrix size needed in the hybrid approach is only 71, which is less than one-sixth of the corresponding size for pure subdomain functions.

REFERENCES

[1] A. H. Chang and R. Mittra, "The Use of Gaussian Distributions as Basis Functions for Solving Large Body Scattering Problems," presented at the 1987 North American Radio Science Meeting, Blacksburg, VA.

[2] J. N. Sahalos and G. A. Thiele, "On the Application of the GTD-MM Technique and its Limitations," *IEEE Trans. Antennas Propagat.*, Vol. AP-29, pp. 780-786, Sept. 1981.

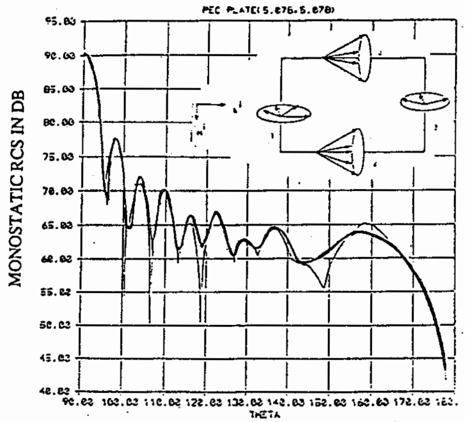

Figure 1. Monostatic RCS for a 5.078 PEC plate.
Thick line - calculated data; thin line - measured data.

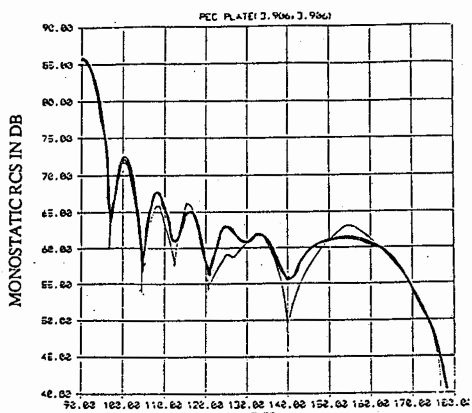

Figure 2. Monostatic RCS for a 3.906 by 3.906 PEC plate.
Thick line - calculated data; thin line - measured data.

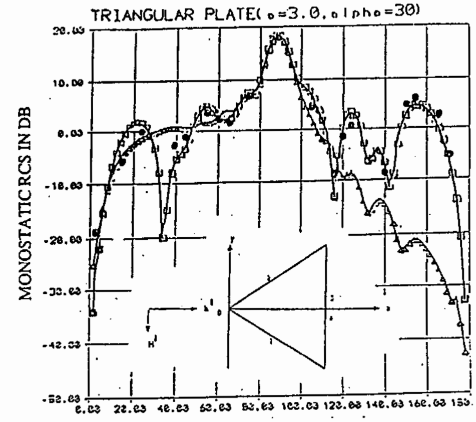

Figure 3. Monostatic RCS for a PEC triangular plate.
—□—□— 461 rooftop subdomain basis functions.
—△— half-plane solutions only.
● measured.

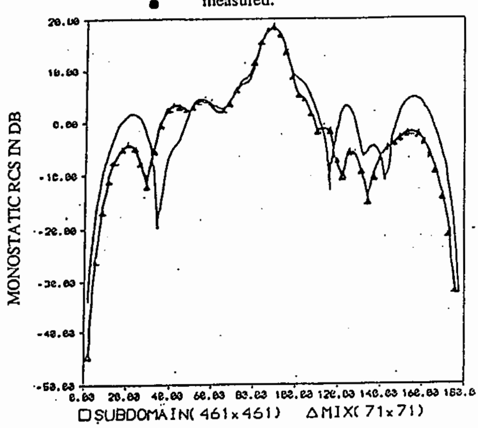

Figure 4. Monostatic RCS for a PEC triangular plate.
——— 461 rooftop subdomain basis functions.
—▲—▲— hybrid method--71 basis functions.

Notes

Wednesday PM

URSI-B Session 62

3-D SCATTERING & DIFFRACTION

Chairmen: D. Sengupta, University of Detroit;
P. Huddelston, McDonnell Douglas

Room: Newhouse 262 *Time*: 1:25-5:00

SCATTERING FROM AN ELECTRICALLY LARGE CIRCULAR CYLINDER OF FINITE LENGTH

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Center for Electromagnetics Research
Northeastern University
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The general problem under investigation is that of determination of the scattered fields from a circular cylinder of finite length illuminated by an incident plane wave from an arbitrary direction and with arbitrary polarization. The radius and length of the cylinder are both comparable to or large compared with wavelength.

The work reported here is confined to the perfectly conducting cylinder. An extension is in progress which includes the effect of a dielectric layer covering the basic cylindrical structure, the latter being a perfect conductor. The extensive literature on scattering from circular cylinders has concentrated largely on the infinitely long cylinder and in some treatments only normal incidence is considered. A search for previous work on circular cylinders of finite length has revealed many treatments using MOM for electrically small cylinders and GTD for electrically large cylinders. Past investigations providing directly useful background information for our work were those of Wait and Hill (Radio Science, Vol. 8, 1973) and Kao (JAP, Vol. 40, 1969).

Our analysis is based on the classical expansion of Hertz vectors into cylindrical vector wave functions. The Z-dependence is based on a Fourier expansion. Boundary conditions are applied on the lateral surfaces and the top and bottom surfaces and the coefficients for TE and TM mode series are determined. The Stratton Chu integral method is used to determine the radiation fields at a remote receiving point. The latter procedure circumvents the necessity for specification of the fields through the mode series in the regions above and below the cylinder. The form of the Stratton-Chu integral including effects of discontinuous fields on the surface is used to account for contributions from the rims at the top and bottom, particularly important at near-axial receiving angles.

Numerical results are shown for backscattering at near-normal and near-axial incidence angles and some angles between these two regions, and for a few values of electrical length, electrical radius and the polarization ratio of the incident field. Comparisons with solutions obtained by MOM, GTD and PTD are discussed.

NUMERICAL SOLUTION FOR SCATTERING AND RADIATION BY A DISCRETE BODY OF REVOLUTION

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and
Donald R. Wilton
University of Houston, Houston, TX 77004

It is well known that geometrical symmetries present in a scatterer or radiator can often be exploited to reduce the computational effort necessary to determine the induced current in moment method solutions of such problems. In this work we examine a common type of rotational symmetry in which the geometrical surface may be rotated about an axis through an angle of $2\pi/K$ into coincidence with itself. We use the term *discrete body of revolution* (DBOR) to describe such a surface. As K becomes large the body approaches a continuous BOR. The procedure essentially requires the expansion of both the current and the excitation into symmetrical components and makes use of the orthogonality between the components to reduce the moment matrix to block diagonal form. Solution of the linear system can be computed a block at a time to obtain the individual modal responses. Occasionally, the desired excitation happens to be one of the symmetrical components, in which case only a single mode needs to be calculated. The composition of the block-diagonal form of the moment matrix can be shown to reduce to the computation of the DFT of selected elements from rows of the original moment matrix. The inverse DFT of the symmetrical components of the surface current is required to finally obtain the actual current at a point on the object.

Numerical results have been obtained for several canonical objects as well as some more practical geometries and comparisons have been made with existing data when possible. Under development is an extension of the approach which allows one to treat problems involving coupling between an object with discrete rotational symmetry and one without symmetry. The approach retains the advantages of subsectional modeling and does not require any special basis function to be developed if the assymetrical object is attached to the DBOR. This appears to be an improvement over coupling an object to a continuous BOR since extensive work is required at the attachment point.

ELECTROMAGNETIC WAVE SCATTERING FROM AN ELLIPTIC DISC

by

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Arlington, Texas ,76019

ABSTRACT

For a plane wave exciting an elliptic disc, Shifrin approximation leads to a scattering amplitude tensor equal to that of the Rayleigh multiplied by a pupil function. The effect of the pupil function on the bistatic cross section is controlled by the incident and the scattered directions , the frequency, and the disc dimensions.

The calculated and the measured values of the like and the cross polarized bistatic cross sections are compared for different incidence angles.

ELECTROMAGNETIC SCATTERING BY CONDUCTING BODIES OF REVOLUTION WITH PARTIAL COATING

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In this paper we consider the problem of electromagnetic scattering by conducting bodies of revolution with one or more layers of partial coatings of possibly lossy dielectic material. The geometry of the problem is shown in Fig. 1. While it is possible to formulate an exact integral equation to solve this problem, the numerical solution of the equation poses several difficulties. For most scatterers of interest, the matrix size is often very large, thus making the solution procedure very expensive if not impossible.

In this paper, an approximate solution procedure for the partially coated body of revolution problem shown in Fig. 1 is presented. The solution procedure assumes that the partial coating extends over the entire surface of the scatterer. The coating is made very very thin over those regions where the coating actually does not exist. This procedure results in a matrix which has a block tri-diagonal nature and this enables one to obtain a solution by working with several smaller matrices rather than one large matrix. However, the assumption of very thin coating causes numerical instabilities in the solution process. Ways to circumvent these instabilities and obtain stable solutions are presented.

Results for bodies of revolution with coatings of a wide range of medium parameters are shown to give accurate results.

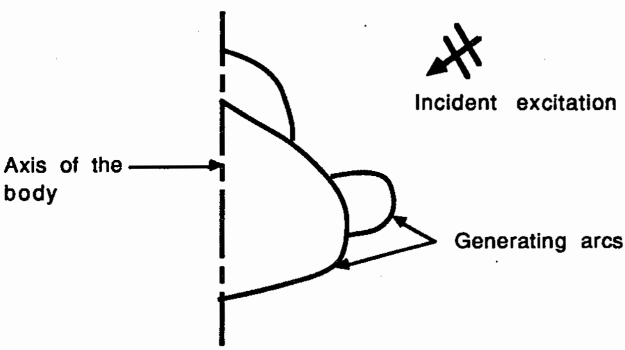

Fig. 1. Geometry of the partially coated body of revolution problem

SCATTERING FROM SURFACE IMPEDANCE OBJECTS COATED WITH PURE DIELECTRICS

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Widespread use of composite material has renewed interest in the electromagnetic effects associated with imperfectly conducting bodies. Imperfectly conducting surfaces characterize many nonmetallic scatterers. The impedance boundary condition (IBC) is a straightforward one, and lead to very useful and expositive results. Basically 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 properties of the surface materials. However, the existence of a pure dielectric material in addition to the imperfectly conducting one requires a consideration of the exact boundary conditions on the dielectric surfaces as such surfaces can not be treated using the impedance boundary condition. Accordingly, in such a case, a different approach in which some kind of mixed boundary conditions are introduced has to be taken. The formulation and implementation of such an approach represent the purpose of this presentation. Surface integral equations are formulated for the problem of impedance surfaces coated with pure dielectric materials. The moment method is then used to reduce the integral equations into a matrix equation for bodies of revolution. The numerical solution obtained is compared with available analytic solutions of a sphere.

ELECTROMAGNETIC SCATTERING BY AN ARBITRARY SHAPED THREE-DIMENSIONAL CONDUCTING BODY WITH A MATERIAL COATING

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This paper introduces a numerical scheme for the analysis and computation of electromagnetic scattering by arbitrarily shaped three-dimensional layered dielectric and/or magnetic bodies, possibly coating a conducting body. The analysis is based on the method of moments and surface field integral equations. In contrast to the usual surface field formulation which employs both magnetic *and* electric surface currents, coupled integral equations are obtained in terms of two equivalent *electric* currents only at each material interface. These currents reside on boundaries between piecewise homogeneous material regions, and each current is associated with the field representation in one of the regions on either side of the boundary. Continuity conditions on tangential E and H are enforced at each material interface, and planar triangular patches are used to model the boundaries of the homogeneous material regions.

The use of electric currents only in the formulation simplifies the calculation of the matrices approximating the integral equation. However, the resulting integral equations do not have a unique solution at all frequencies. At least in the case of a conductor with a single layer of coating material, it is found that this deficiency is eliminated by the use of a combined field boundary condition at the conductor surface. Comparison with the classical Mie series solution for the radar cross section of a sphere coated with one or more material layers shows that the approach yields good accuracy. Partially coated conductors are also treated and these are validated by analyzing a partial "vacuum" coating which, of course, should yield results identical to that of the uncoated conducting scatterer.

A VOLUME INTEGRAL FORMULATION FOR ELECTROMAGNETIC SCATTERING FROM THIN DIELECTRIC SUBSTRATES

Mark J. Povinelli* and Roger F. Harrington
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This paper presents a volume integral formulation in conjunction with a method of moments solution for scattering from two– and three–dimensional homogeneous dielectric sheets. The polarization current is expanded in terms of divergence–free expansion functions. These functions give rise to no volume distribution of polarization charge, but produce a surface distribution of polarization charge where they have a normal component at the surface. The surface charge is related to the volume current by the equation of continuity. The elements of the generalized impedance matrix initially involve integrals of $\mathbf{E}_m \cdot \mathbf{J}_n$ over the subsections, but when integrated by parts they become integrals of $-j\omega(\mathbf{A}_m \cdot \mathbf{J}_n + \phi_m\sigma_n)$. Here $\mathbf{A}_m$ is the vector potential from a current expansion function $\mathbf{J}_m$, and ϕ_m is the scalar potential from a charge expansion function σ_m. This choice of expansion functions assures that all singular integrals are absolutely integrable. It also results in a more accurate model for determining the near fields, such as required for the analysis of printed circuit antennas, scatterers, and transmission lines on thin dielectric substrates.

The expansion functions are chosen as circulating current loops. When these loops terminate on the surface, they give rise to surface charge doublets. For two–dimensional problems the dielectric sheet is divided into square subsections, and for three–dimensional problems it is divided into cubic subsections. The current loops are taken to be rooftop functions combined so that the volume charge density vanishes. To simplify the integrals a pulse approximation to the rooftop functions is used. Also the second integrations are approximated by the value of $\mathbf{A}_m \cdot \mathbf{J}_n$ or $\phi_m\sigma_n$ at the center of a subsection times the area or volume of the subsection. Care must be taken to ensure that the expansion functions are linearly independent, or else the impedance matrix becomes singular.

The TE scattering solution to a square post and a thin slab are computed and compared to a surface equivalence formulation and to other numerical results. The results for electromagnetic scattering from a three–dimensional dielectric cube are also shown and compared to a surface equivalence solution.

COMBINED FIELD FORMULATION FOR AXIALLY INHOMOGENEOUS BODIES OF REVOLUTION

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An electromagnetic scattering formulation is developed for a general body of revolution (BOR) having axial inhomogeneities. The formulation incorporates a combined field integral equation (CFIE) for the above case. It treats the following as subcases: (a) perfectly conducting scatterers, (b) conducting scatterers with layered dielectric coatings, (c) partially coated scatterers, and (d) axially inhomogeneous partially penetrable bodies.

The boundary conditions at the various discontinuities and regions of the body are rigorously implemented for arbitrary BORs. The present analysis allows surface coatings of nonuniform thickness that are multilayered and characterized by both a complex permeability and permittivity. A unifying integral operator scheme is used to reduce the complexity of the equations and facilitate computer implementation of the CFIE formulation using the method-of-moments (MM) Galerkin technique.

Extensive validation of the CFIE formulation for the cases noted above is presented. For comparison, both published and in-house experimental data are used. Representative examples of the CFIE results for monostatic and bistatic scattering will be given for each of the foregoing subcases and contrasted with earlier published results based on non-combined formulations.

INTERACTION OF EM FIELDS WITH THREE-DIMENSIONAL HETEROGENEOUS BODIES

Xiaoyi Min* and K.M. Chen
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Michigan State University, East Lansing, MI 48824

We consider a three-dimensional heterogeneous body, which contains a number of dissimilar regions each of which has constant permittivity, permeability and conductivity, being exposed to an impressed EM field. The induced electric and magnetic fields at any point inside the body are to be determined. To determine these quantities, we first determine the equivalent electric surface current and equivalent magnetic surface current defined on all the interfaces between dissimilar regions within the heterogeneous body. A set of coupled surface integral equations for these equivalent surface currents have been derived, and they are solved numerically.

In the numerical solution, the interfaces are partitioned into triangular patches, and the equivalent surface currents are expressed in terms of two-dimensional vector basis functions. The same vector basis functions are used as testing functions to transform the coupled surface integral equations into a system of linear equations for the unknown coefficients of the vector basis functions.

Once the equivalent electric and magnetic surface currents on the interfaces are determined, the induced electric and magnetic fields at any point within the heterogeneous body can be readily computed from the surface integrals involving these equivalent surface currents.

Numerical results are verified by the exact solutions of simple heterogeneous bodies such as a concentric sphere.

Thursday AM

URSI-B Session 63

DIELECTRIC WAVEGUIDES

Chairmen: R. E. Collin, Case Western Reserve University;
N. Buris, North Carolina State

Room: Sheraton Amphitheater *Time*: 8:25-12:00

RADIATION FIELD OF THE DIELECTRIC-FIBER WAVEGUIDE-- A DIRECT COMPLEX-ANALYSIS APPROACH

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East Lansing, Michigan 48824

The complete propagation-mode spectrum of the circular dielectric-fiber waveguide consists of discrete surface-wave fields and continuous radiation-field spectral components; the former have been studied exhaustively, but the latter require further attention. The radiation field is central to excitation and scattering studies, and an alternative to the conventional eigenfunction-expansion approach to its construction is exposed. It is demonstrated, for a step-index guiding region immersed in a uniform surround, that a 2-d transform-domain Green's function may be used to construct impressed fields $\mathbf{e}^i,\mathbf{h}^i$ maintained by impressed current $\mathbf{j}$ located in either region. When the impressed fields interact with the guiding structure, scattered fields $\mathbf{e}^s,\mathbf{h}^s$ are excited. Total tangential fields are matched at the interface; separable boundary conditions lead to an exact solution for the radiation-spectrum fields, including their excitation amplitudes.

All analysis is performed in the axial Fourier-transform domain where quantities, e.g. $\mathbf{e}(\rho,\zeta) = F_z\{\mathbf{E}(\rho,z)\}$, are transforms depending upon transform variable ζ. Impressed current $\mathbf{j}(\rho,\zeta)$ maintains the impressed fields

$$\begin{Bmatrix} \mathbf{e}^i(\rho,\zeta) \\ \mathbf{h}^i(\rho,\zeta) \end{Bmatrix} = \int_{CS} \bar{\bar{g}}^{e}_{\zeta}{}^{h}(\rho|\rho')\cdot \mathbf{j}(\rho',\zeta)\,dS'$$

where Green's dyads are circular-harmonic expansions modulated by $\exp(jn\phi)$. Similar expansions are exploited to represent scattered fields $\mathbf{e}^s(\rho,\zeta),\mathbf{h}^s(\rho,\zeta)$ in the guiding (J_n Bessel series) and surround (H_n Bessel series) regions. The total fields in either region are $\mathbf{e}=\mathbf{e}^i+\mathbf{e}^s$ and $\mathbf{h}=\mathbf{h}^i+\mathbf{h}^s$, where the impressed fields are non-vanishing only in the region containing the excitatory current. Tangential fields are matched at the guiding-region/surround interface. Orthogonality of the $\exp(jn\phi)$ leads to a system of 2N+1 forced 4x4 matrix equations (N = total number of circular harmonics retained) $[E_{mn}(\zeta)][a_n(\zeta)]=[f_m(\zeta)]$ which can be solved independently for the unknown expansion coefficients $a_n(\zeta)$.

The spatial field is recovered as $\mathbf{E}(\rho,z)=F_z^{-1}\{\mathbf{e}(\rho,\zeta)\}$. Evaluation of the inversion integral by appropriate ζ-plane analysis yields the complete propagation-mode spectrum excited by $\mathbf{j}$. Integration around branch cuts associated with branch points $\pm k_s$ leads to the radiation fields as a superposition of forced spectral solutions to the reduced system of independent matrix equations. These radiation fields permit the construction of an electric dyadic Green's function useful in the study of excitation and scattering problems associated with circular-fiber waveguides.

Improved Treatment of Intrinsic Modes for Tapered Dielectric Waveguides

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and

L.B. Felsen
Dept. of Electrical Engineering and Computer Science
Weber Research Institute
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Wave propagation in tapered dielectric waveguides poses nonseparable boundary value problems. For wedge-shaped tapers, it has been shown that it is possible to construct spectral objects, named intrinsic modes, which are exact source-free solutions of the wave equation in the interior and exterior domains excluding the apex [J.M. Arnold and L.B. Felsen, Radio Sci. 19 (1984), 1256-1264]. It has also been shown that simplifying asymptotic approximations for small taper angles reduce the exact intrinsic mode integrals to the local (adiabatic) mode in the trapped regime before cutoff while providing the necessary uniformization through cutoff when the mode propagates toward the narrowing portion. This simplified form is inadequate for larger tapers, where total energy conservation is no longer found to be satisfied, especially during and after the cutoff transition that converts the trapped mode energy into radiation. The problem has now been re-examined by restructuring the exact integral form so that it emphasizes the initially employed multiple reflected plane wave spectra inside the taper instead of their collective combination into local mode type fields. This turns out to lead to a readily computable form, whose convergence improves with increasing taper angle while preserving energy conservation. Numerical results based on the small angle asymptotic and the complete intrinsic mode forms show the improvement obtained by the latter when the former becomes deficient. Taken together, the two formulations allow efficient numerical treatment, with corresponding physical understanding, of a broad range of wave phenomena associated with wedge-tapered guiding regions.

AN AMBIGUITY IN THE EIGENVALUE PROBLEM FOR DIELECTRIC WAVEGUIDES AND RESONATORS

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The behavior of dielectric waveguides and resonators can be summarized through the identification of the propagating and resonant modes. To permit the effective use of computer aided design packages a numerically efficient technique is then needed to identify these resonant and propagating modes. Such a techniques has recently been described (Collin and Ksienski, Radio Science, December 1987) which is based upon the boundary element formulation. The identification of the mode is achieved by solving the eigenvalue problem, which numerically corresponds to finding the zeroes of a determinant. A result of this procedure is that in formulating the determinant an inverse or dual problem is also incorporated. The resulting spurious solutions are not a result of discretization or the choice of basis functions but in fact depend upon the boundary conditions which are imposed upon the dyadic Green's functions used in the integral equation formulation. The effect of several choices of boundary conditions for the Green's functions will be shown for the dielectric waveguide and resonator and a physical interpretation of the spurious solutions will be presented.

DETERMINATION OF THE ATTENUATION CONSTANT FOR A LEAKY-WAVE ANTENNA IN NON-RADIATIVE DIELECTRIC WAVEGUIDE

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A longitudinal slot in one of the side walls of a Non-Radiative Dielectric (NRD) waveguide has been shown to be an efficient leaky-wave antenna (Malherbe, E. Lett., vol. 22-9, 24 Apr. 1986). An analytical method of solving for the attenuation constant in this NRD structure will be presented.

Goldstone and Oliner (IRE Trans., vol. AP-7, Oct. 1957) described a solution for rectangular waveguide by first analizing the transverse cross section of the guide and then applying transverse resonance in order to obtain the axial wavenumber. However, in the case of a metal waveguide, only the dominant mode can propogate in both the transverse and axial directions; all other modes are below cutoff. In the NRD waveguide, all modes present can propagate in the transverse x-direction, even though only the dominant surface mode is above cutoff for the axial z-direction (fig.1).

In order to solve this problem, the transverse resonance condition for each mode present must be solved simultaneously for all modes at the boundaries, one of which includes the slot. To make the problem tractable, the infinite number of modes are discretized by introducing metal surfaces across the open sides of the NRD guide at an appropriate distance away from the dielectric slab (fig. 2). Under the assumption of a constant electric field in the slot, an integral equation is derived and solved numerically to approximately determine the transverse magnetic field on the slotted side wall. This yields the transverse wavenumbers, which are used to calculate the axial attenuation constant.

Computed results will also be compared to measurements.

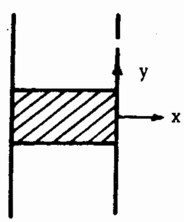

Fig. 1

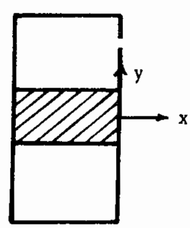

Fig. 2

ANALYZING INFINITE STRIP UNSTABLE OPTICAL RESONATORS USING DIFFERENT TECHNIQUES

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(On sabbatical leave from Shiraz University, Shiraz, Iran)

Unstable Optical resonator is used in medium and high power laser. In stable resonator when Fresen number is greater than 0.5 all of the energy is not absorbed by 1st mode but energy is absorbed in higher order modes. In unstable resonator with proper gain it is possible to have mode with lowest power loss and this mode will absorbe most of the energy from the laser material and it is possible to have optical resonator with smaller length. For this reason power loss calculation is important in unstable optical resonators.

At first Fox and Li calculated power loss in infinite strip cylinderical and spherical resonators with circular aperature for Fresnel number greater than 10 by scalar theory of diffraction using interative method (Fox, A.G. and Li, T.H. 1964. Quantum Electronic III, 8, 1262). By using geometrical optics Siegman calculated power loss in optical resonators for large Fresnel number (Siegman, A.E. 1965, Proc. IEEE. 53, 277). Sanderson and Striefer calculated power loss by Gaussion Quadrature and Cornu spiral methods (Sanderson, R.L. and Streifer, W 1969. Appl. Opt. 8, 2129). In the first method the integral is converted to a matrix. Using QR-method eigen value and eigen vector of the matrix is evaluated. Eigen vectors are electric field modes and power loss in each mode is equal to one minus absolute value of the eigen value of that mode. Siegman and Miller found eigen values for spherical resonator with circular aperture with Fresnel number greater than 13 using Prony's method (Siegman, A.E. and Miller, H.Y., 1970. Appl. Opt. 9, 2729). Santana and Felsen calculated eigen value using waveguide theory (Santana, C. and Felsen, L.B. 1976. Appl. Opt. 9, 1470).

As Fresnel number gets larger resulting series from the integral has more elements. The number of elements in the series is usually between 6 to 10 times the Fresnel number (Siegman, A.E. and Miller, H.Y. 1970. Appl. Opt. 9. 2729). So power loss evaluation in optical resonators with Fresnel number greater than 10 takes a long time. Except Santan and Felson (Santana, C. and Felsen, L.B. 1976. Appl. Opt. 9, 1470) all of the works which is done based on scalar theory of diffraction. In this paper physical optics in exact form and with Fresnel approximation, scalar theory of diffraction without approximation, geometrical theory of diffraction and physical theory of diffraction are used in analyzing and power loss calculation of infinite strip unstable optical resonators.

Markku I. Oksanen
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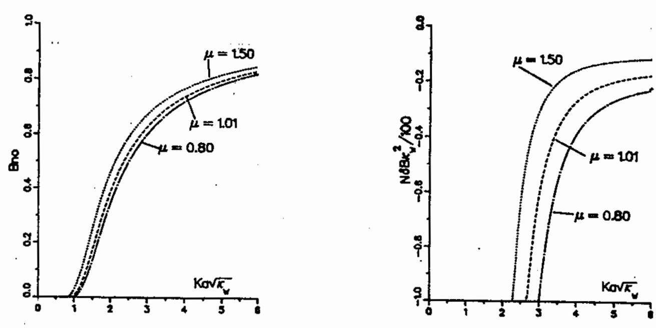
In this report dispersion curves and birefringence in a uniformly bent weakly-guiding anisotropic optical fiber are studied. The analysis is concentrated on geometrical effects to the birefringence, thus neglecting modifications due to the bend in waveguide cross-section or in the dielectric properties of the guide. The theory is applied for curved step-index and parabolic-index fibers. Two different kinds of anisotropic fibers, whose solutions can be obtained from whose of the isotropic fibers by transformation equations are considered.

The analysis starts by deriving a second-order vector differential equation for the transverse field in a curved anisotropic waveguide. In a straight guide the field is an even and the propagation constant an odd function of α, where α^2 equals to the relative difference between the dielectric constans in a core and a cladding. These are combined with the asymptotic series of the curved guide: the field is a power series of (a/R_0), whereas the propagation factor is proportional to $(a/R_0)^2$. R_0 and a are radii of the curvature and the core, respectively. These are inserted in the differential equation and coefficients of different powers of α and (a/R_0) are equated. Thus, asymptotic equations for the curved fiber in the limit of weak guidance and large radius of curvature are obtained. Birefringence relations are then derived for curved anisotropic guides. The isotropic guide is seen to be more difficult to handle because of degenerate solutions of the basic mode.



Normalized birefringence B_{no} of the straight anisotropic parabolic-index fiber and the change δB due to the curvature as functions of normalized frequency. μ is the ratio of the transverse anisotropy constants κ_v/κ_w and $N = (4R_0\alpha^2/a)^2$.

RADIATION AND TRANSMISSION OF ELECTROMAGNETIC FIELDS IN A CIRCULAR BEND OF A SLAB WAVEGUIDE

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Osaka University, Suita-shi, Osaka, 565 Japan

Rigorous theory is established for analyzing radiation and transmission of electromagnetic fields in the uniformly bent section of a slab waveguide. In this theory, general fields are expressed in the form of spectral integral of continuous modes. The fields of the continuous mode satisfy necessary boundary conditions at the curved waveguide boundaries, but not satisfy the radiation condition individually. These properties are the same as those of the "radiation mode" of open-type waveguides. Numerical examples are presented for calculating transient fields in a circular bend when TE_0 mode is incident from the straight guide connected to the bend (See Fig.1). Radiated field patterns are depicted in Fig.2 for radius of curvature R being 5.0, 1.0, and 0.5cm, normalized frequency $V(=2k_0a\sqrt{n_1^2-n_2^2})$ being 2.0, and refractive indexes n_1 and n_2 being 1.50375 and 1.5, respectively, where k_0 is the free-space wave number and 2a is the guide width. We see from Fig.2 that most of the incident power disappears till the angle ϕ around 120-130° if the bending is very sharp such as the case of R=0.5cm, while if the bending is gentle such as the case of R=5.0cm, a kind of guided mode with steady radiation loss is formed after passing through the region where unsteady radiation occurs. Figure 3 shows the radiation of field distribution as the field travels along the bend, where R=0.5cm. Two vertical solid lines mean the waveguide boundaries. It is seen from Fig.3 that the field rapidly goes out of the guide since the bending is very sharp in this case.

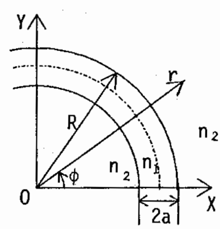
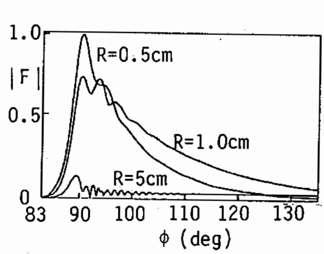


Fig.1 Circular bend.



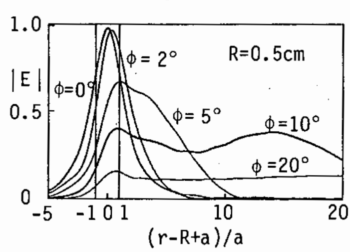


Fig.2 Radiated field patterns. Fig.3 Field distributions.

QUASI-OPTICS OF THE EVANESCENT WAVE EXCITATION OF PLANAR DIELECTRIC WAVEGUIDES

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The governing equations for the evanescent wave excitation of the guided mode in a planar dielectric waveguide are derived using a quasi-optical technique. The coupling between the prism dielectric and the film waveguide is assumed to be weak. The factor by which the field decays from the surface of the film waveguide to the surface of the prism dielectric is chosen to be the small parameter for ordering the various field quantities. Even though the power in the incident wave is larger than that in the guided mode, the guided mode amplitudes defined at the film surfaces are assumed to be of the order of unity, and the incident-, the reflected-, and the transmitted-wave amplitudes defined at the surface of the prism dielectric are assumed to be weaker by one order in the small parameter. Justification is provided for this type of ordering of the field amplitudes.

The governing equations are in their canonical form, and they are consistent with the requirements of reciprocity and power conservation. Few important results obtained from the solution of the governing equations are summarized.

ON THE COUPLING LENGTHS BETWEEN TWO CIRCULAR CYLINDRICAL DIELECTRIC WAVEGUIDES: EXACT SOLUTION VERSUS COUPLED-MODE ANALYSIS

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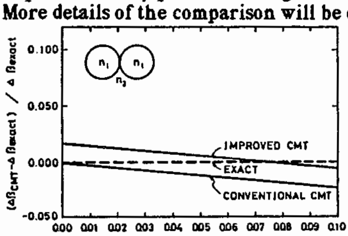
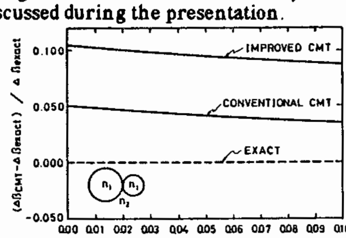
The evanescent wave coupling between optical dielectric waveguides, e.g., optical fibers, has often been analyzed by using the coupled-mode formalism. Recently, the formulation of coupled-modes has undergone more thorough examination and a set of improved coupled-mode equations has been derived (A. Hardy and W. Streifer, J. Lightwave Technol., LT-3, 1135-1146, 1985). However, the accuracy of this new analysis against that of the conventional coupled-mode theory for the case of coupling between two circular cylindrical dielectric guides is still not well understood. The purpose of this paper is to present a detailed comparison among the predictions of the exact solution, the conventional coupled-mode theory, and the improved coupled-mode theory for the coupling between two parallel single-mode optical fiber cores. Our study emphasizes on how the accuracy of the perturbation methods would change as the guiding strength of the waveguides become greater. We consider touching cores and the two cores may be indentical or nonidentical. We first solve the exact normal modes for the coupled system by employing circular harmonics expansion and matching the core-cladding boundary conditions (W. Wijngaad, J. Opt. Soc. Amer., 63, 944-950, 1973). The even and odd modes obtained have the propagation constants β_{even} and β_{odd}, respectively, and we define $\Delta\beta_{exact}$ as $\beta_{even}-\beta_{odd}$. Then, we calculate $\Delta\beta$ from the coupled-mode theories and designate it as $\Delta\beta_{CMT}$. The LP_{01} modes are employed for the coupled-mode analysis. Figs. 1 and 2 show the numerical results for which the normalized frequency is fixed as V=2 for the larger core and V=1.33 for the smaller core. The errors in $\Delta\beta_{CMT}$ as compared to $\Delta\beta_{exact}$ are plotted as functions of the parameter δ, defined as $\delta=1-(n_2/n_1)^2$, where n_1 and n_2 are the core and cladding refractive-indices, respectively. We take n_1=1.458 and the light wavelength λ=1.3 μm. It is found that the coupled-mode analyses are more suitable for the identical-core cases. Fig. 1 shows that whether the improved theory is better depends on the waveguide structure. Fig. 2 shows that both of the perturbation analyses overestimate the coupling strength. Moreover, both figures indicate that the improved theory predicts stronger coupling than the conventional theory does. More details of the comparison will be discussed during the presentation.



δ Fig. 1



δ Fig. 2

Thursday AM

URSI-B Session 64

MICROSTRIP CIRCUITS

Chairmen: J. Kong, MIT; J. Mosig, Ecole Polytechnique

Room: Sheraton Regency A *Time*: 8:25-12:00

8:30	**Reflection and Transmission Operators for Strips and Disks Embedded in Homogeneous and Layered Media** W. C. Chew, L. Gurel, University of Illinois	312
8:50	**A New Method For Discontinuity Analysis In Shielded Microstrip: Theoretical and Computational Considerations** L. P. DunLeavy, P. B. Katehi, University of Michigan	313
9:10	**The Vertical Coaxial Probe in a Microstrip Substrate** R. C. Hall, J. R. Mosig, F. E. Gardiol, Ecole Polytechnique Federale de Lausanne-LEMA	314
9:30	**Resonance in Cylindrical-Rectangular and Wraparound Microstrip Resonators** S. M. Ali, M.I.T.; T. M. Habashy, Schlumberger-Doll Research; J. A. Kong, M.I.T.	315
9:50	**Leaky Modes of Microstrip Transmission Lines** J. M. Grimm, J. S. Babgy, University of Texas at Arlington	316
10:10	**COFFEE BREAK**	
10:40	**Computer Aided Engineering Of Microwave Microstrip Filters And Amplifiers** J. A. Soper, Michigan Technological University	317
11:00	**The Analysis Of Coupled Microstrip Transmission Lines With EFIE Method** C. Lee, J. S. Bagby, The University of Texas at Arlington	318
11:20	**Dispersion Characteristics Of Shielded Microstrip Lines Crossed By Periodic Metallic Strips In Multilayered Anisotropic Media** S. M. Ali, C. W. Lam, J. A. Kong, MIT	319
11:40	**Guidance or Resonance Conditions for Strips and Disks Embedded in Homogeneous and Layered Media** L. Gurel, W. C. Chew, University of Illinois	320

REFLECTION AND TRANSMISSION OPERATORS FOR STRIPS AND DISKS EMBEDDED IN HOMOGENEOUS AND LAYERED MEDIA

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ABSTRACT

In this paper, we introduce a new notation to simplify the solution of scattering by strips or disks. We make use of vector Fourier transforms (Chew and Habashy, IEEE Trans. Antennas Propag., vol. AP-34, pp. 871-879, July 1986) and introduce a double-dot product for inner products in uncountable, infinite dimensional, linear vector space. We characterize the scattering by a strip or a disk with a reflection operator and a transmission operator that relate the continuum of scattered waves to a continuum of incident waves. After the reflection operator for a single strip or disk is derived, we show how the reflection operator for a strip or disk in the presence of another reflecting medium, e.g., a layered medium, can be derived. The scattering by N strips or disks in a homogeneous medium is also presented. Next, we show the derivation of the reflection operator for an embedded strip or disk in a layered medium. Furthermore, we discuss how we can find the reflection operator for N strips or disks embedded in a layered medium. As a corollary, we derive the reflection and transmission operators for a slot or an aperture. These operators have applications in a number of scattering, guidance and resonance problems as in microwave integrated circuits, high speed circuitries, microstrip antennas and radar scattering cross-sections.

A NEW METHOD FOR DISCONTINUITY ANALYSIS IN SHIELDED MICROSTRIP: THEORETICAL AND COMPUTATIONAL CONSIDERATIONS

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Electrical Engineering and Computer
Science Department
Ann Arbor, MI 48109

ABSTRACT

A new integral equation method has been developed for the accurate full-wave analysis of shielded microstrip discontinuities. In most circuit applications, radiation and electromagnetic interference are avoided by enclosing microstrip circuitry in shielding boxes (or housings). At microwave and millimeter-wave frequencies, accurate analytical techniques are required that take into account the shielding box as its effects can be significant.

The new method, described herein, accurately models the effects of shielding in the computation of microstrip discontinuity parasitics. The theoretical formulation involves a unique combination of the reciprocity theorem, and transmission line theory. To examine the validity and convergence of the numerical solution using the above mentioned theory several numerical experiments were carried out. The results from these experiments lend considerable insight into the optimum choice of computational parameters for best convergence and stability. The theoretical derivations and conclusions will be discussed extensively. Furthermore, to demonstrate the method, numerical results will be presented for open-end and series gap discontinuities.

This work was sponsored by The National Science Foundation and the Microwave Products Division of Hughes Aircraft Co. as part of a cooperative research program with The University of Michigan (Contract No. ECS-8602530)

THE VERTICAL COAXIAL PROBE IN A MICROSTRIP SUBSTRATE

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CH-1015 Ecublens, Switzerland

The problem of a coaxial probe passing through a grounded microstrip substrate must be solved accurately before the feed region of a coaxial fed microstrip antenna can be completely described. Previous models of the feed region have been simple and have used a correction term that is added to the input impedance to correct for the substrate thickness. These correction terms are valid for thin substrates. However, since there is a trend to thicker substrates to achieve greater bandwidth a more accurate model is needed that takes into account the current distribution on the coaxial probe. The model described here employs the Method of Moments to compute the currents on a vertical coaxial probe that could be used as a feed for a microstrip antenna. The model is computationally intense yet highly accurate.

The structure analyzed consists of a small diameter coaxial probe extending out of a highly conducting ground plane that is covered with a layer of low loss dielectric material. The coaxial probe extends from the ground plane up to the top of the dielectric layer where it could be attached to a microstrip antenna. A possible junction attachment basis function will be presented.

A mixed potential integral equation (MPIE) is written to describe the current distribution on the probe. The vector and scalar potentials are in general Sommerfeld-type integrals. The formulation and numerical evaluation of these integrals will be briefly described. A magnetic current frill is used to model the coaxial aperture in the ground plane that produces the excitation fields.

Calculated results to be presented include the vector and scalar potentials, the input impedance of isolated probes and the coupling between neighboring probes as a function of permittivity, thickness and separation. A similar study has been performed by Chi and Alexopoulos (IEEE Trans. AP-34, pp. 1080-1091, 1986). The results computed using the MPIE formulation described here will be compared to those published.

RESONANCE IN CYLINDRICAL-RECTANGULAR AND WRAPAROUND MICROSTRIP RESONATORS

S.M. Ali[*], *T.M. Habashy*[+], *and J.A. Kong*[*]

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Cylindrical microstrip structures are important in applications where they can be flush-mounted on curved surfaces, e.g., space vehicles, missiles, rockets, etc. The study of their resonances is useful in determining their bandwidth which is an important parameter in the design of such structures. Previous papers (e.g., C.M. Krowne, *IEEE Trans. Antennas Propagat.*, vol. AP-31, no. 1, pp. 194-199, Jan. 1983) have calculated the resonant frequencies of microstrip elements on cylindrical structures using a magnetic wall cavity model, thus ignoring fringing field effects. In such an analysis, the resonant frequencies obtained are purely real and therefore do not account for radiation loss, thus limiting the validity of the obtained results to very thin substrates.

In this paper, we rigorously formulate the resonance problem of both the cylindrical-rectangular and the wraparound structures using a full wave approach based on a cylindrically stratified medium formulation. This analysis leads to a vector integral equation which can then be solved using Galerkin's method. The resulting nonlinear eigenvalue equation is then solved numerically. Both the real and imaginary parts of the resonance frequency are computed as a function of the substrate thickness. The effect of other parameters (e.g., the patch's dimensions, the substrate's dielectric constant, etc.) is also investigated. An independent perturbative approach based on the single mode approximation is also used to compute the complex resonance frequencies in the small substrate thickness limit. It is shown that this perturbative expression for the resonance frequency can be obtained as a limiting case from the exact eigenvalue equation.

Leaky Modes of Microstrip Transmission Lines

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Department of Electrical Engineering
University of Texas at Arlington, Arlington TX 76019

Leakage of surface waves from microstrip structures has long intrigued researchers in the field. This leakage occurs whenever a natural mode of the microstrip has the real part of its propagation constant less than any of the eigenvalue of the background structure surface wave modes. For leaky modes of an integrated microstrip transmission line, the axially-transformed surface current $\overline{k}(\overline{\rho}|\overline{\rho}'; \zeta_m)$ satisfies the homogenous dyadic integral equation:

$$\hat{t} \bullet (k_c^2 + \nabla\nabla\bullet) \oint_L \overleftrightarrow{g}(\overline{\rho} \,|\, \overline{\rho}'; \zeta) \bullet \vec{k}(\overline{\rho}';\zeta) \; dl = 0, \qquad \overline{\rho}' \in L$$

where $\overline{g}(\overline{\rho}|\overline{\rho}'; \zeta_m)$ is the transformed Hertzian potential Green's dyad of the background structure, k_c is the wavenumber in the cover region, ζ is the complex propagation constant of the mode, and L is the cross-sectional contour of the transmission line.

The Green's dyad components are given as inverse Fourier transforms with respect to ξ, the transform variable corresponding to the x-direction. These inversion integrals assume the form of Sommerfeld integrals, and contain the surface wave singularities that are excited by the leaky wave phenomenon, thus being extremely difficult to evaluate by typical techniques. Making use of the Cauchy Integral theorem allows us to calculate the Green's dyad components as a sum of the residues at surface wave pole singularities plus an integration along a hyperbolic branch cut in the complex-ξ plane.

In this formulation, the residue terms correspond to contributions of the surface-wave modes; the branch integral corresponds to the contribution of the continuous radiation spectrum. This formulation allows easy identification of lossless and leaky modes, as the hyperbolic nature of the branch cut in the complex-ξ plane depends only on the mode leakage into the film layer.

ABSTRACT

COMPUTER AIDED ENGINEERING OF MICROWAVE MICROSTRIP FILTERS AND AMPLIFIERS

Jon A. Soper
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Michigan Technological University

A senior level elective course emphasizing computer-aided design of microwave filters and amplifiers is described. Over the twelve year history of the course computer programs have been developed for both microstrip filter and amplifier design. The filter programs are introductory and do not compensate for line junction, end or radiation effects etc. The output is the response of the filter developed. The amplifer programs use graphic Smith chart analysis and are interactive for the design of matching networks. The output is the amplifier network and its response. The programs can be run on either IBM-PCs or Hewlett-Packard 9836 engineering work stations. Approximately 20 electrical engineering students take this course each year.

THE ANALYSIS OF COUPLED MICROSTRIP TRANSMISSION LINES WITH EFIE METHOD

C. H. Lee* and J. S. Bagby
Department of Electrical Engineering
The University of Texas at Arlington, Arlington, TX 76019

A system of exact coupled dyadic integral equations is utilitized in the analysis of propagation in uniform coupled integrated microstrip transmission lines. The dispersion properties and the current distributions of the coupled structures for different spacings and material parameters are presented.

In the case of natural modes of coupled uniform integrated microstrip transmission lines, the axially transformed surface current $\overline{\mathbf{k}}_i(\overline{\rho}'; \zeta)$ satisfies the homogeneous dyadic integral equation:

$$\hat{t} \bullet \sum_{i=1}^{N} \int_{L_i} \overleftrightarrow{g}^{e}(\overline{\rho} \,|\, \overline{\rho}'; \zeta) \bullet \vec{k}_i(\overline{\rho}'; \zeta) \; dL' = 0, \qquad \overline{\rho} \in L_i, \quad i = 1,2, ..., N$$

where $\overline{\mathbf{g}}\,(\overline{\rho} \,|\, \overline{\rho}'\,; \zeta)$ is the transformed Hertzian potential electric field Green's dyad of the background structure, $\overline{\mathbf{k}}_i(\overline{\rho}'; \zeta)$ is the transformed surface current on the i'th line, ζ is the complex propagation constant of the mode, and L_i is the cross-sectional contour of the i'th line.

Conventional electrostatic analyses of this kind of structures result in approximate solutions which are adequate for relatively low speed, low density circuits. However, the analysis presented here results in an exact solution, and can accurately predict the radiative leakage and coupling phenomena of the coupled microstrip transmission line systems.

Numerical results for both coupled and isolated, narrow and wide microstrip transmission line structures are given for comparison purposes.

Dispersion Characteristics of Shielded Microstrip Lines Crossed by Periodic Metallic Strips in Multilayered Anisotropic Media

S. M. Ali, C. W. Lam, and J. A. Kong

Department of Electrical Engineering and Computer Science
and Research Laboratory of Electronics
Massachusetts Institute of Technology

In microelectronic computer packaging, a problem of practical interest is the study of propagation characteristics of a shielded microstrip line in the presence of crossing strips.

In this paper, the microstrip line and the crossing strips are placed at two different interfaces of a three-layer medium bounded by two parallel conducting plates as shown in Fig. 1. The crossing strips are assumed to be periodic and the three layers to be uniaxially anisotropic.

The network analytical method of electromagnetic fields is applied for the hybrid-mode analysis of the frequency dependent characteristics of the structure. The transverse fields in each region are expressed by their Fourier transform in the x-direction and a Floquet harmonic representation in the y-direction. Using Maxwell's equations and applying boundary conditions, we obtain a set of coupled integral equations for the current distributions $\bar{J}_{s_1}$ and $\bar{J}_{s_2}$ on the microstrip line and the crossing metallic strips, respectively.

The determinantal equation for the dispersion relation can be derived by applying Galerkin's procedure to the derived set of coupled integral equations. The Brillouin diagrams are obtained numerically by seeking the roots of the obtained eigenvalue equation. The stop-band properties are numerically presented as a function of the spacing, length, and width of the crossing metallic strips. The effects of the material and geometrical parameters are also investigated.

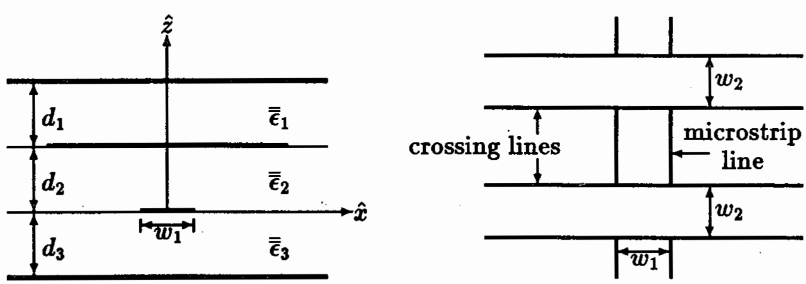

Fig.1 Geometry of the structure

GUIDANCE OR RESONANCE CONDITIONS FOR STRIPS AND DISKS EMBEDDED IN HOMOGENEOUS AND LAYERED MEDIA

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ABSTRACT

We illustrate how the guidance or resonance conditions of strips or disks embedded in layered media can be formulated easily using a new notation we developed. We show that once we know the reflection operator of a reflecting medium, we can find the guidance or resonance conditions of this structure quite easily. We can also find the guidance or resonance conditions when the reflecting medium is interacting with another strip or disk. This has a number of applications in microwave integrated circuits like microstrip transmission lines, microstrip antennas, etc. We illustrate this with the calculations of the guidance in a microstrip line with an infinite ground plane and with a finite ground plane. We also illustrate the application of this to the resonance of a microstrip disk with a finite ground plane. Our results for the infinite ground-plane case agree very well with previous calculations on these problems, while the results for the finite ground-plane case are new. When the width of the of the finite ground plane is equal to that of the upper strip, it is equivalent to placing an infinite ground plane midway between the two strips. Hence, this case is equivalent to an infinite ground plane case with a dielectric slab half as thick. Therefore, its effective dielectric constant is smaller than when the ground plane is infinite. However, as we increase the width of the ground plane, the effective dielectric constant goes through a peak which is above the effective dielectric constant of the infinite ground-plane case, and finally converges to that value from above rather than below.

Thursday AM

Joint AP-S, URSI-A Session 65

NEAR FIELD RCS MEASUREMENTS

Chairmen: D. Falconer, SRI; A. Yaghjian, RADC

Room: Sheraton Regency B *Time*: 8:25-12:00

OVERVIEW OF NEAR-FIELD RCS PROBLEM

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SRI International
Menlo Park, CA 94025 USA

RCS engineers often find it necessary to make scattering measurements in the near field of their target, i.e., at ranges R < $2D^2/\lambda$, where D is the maximum dimension of their target and λ the radiation wavelength. In the near zone the target's RCS pattern will vary with R and may differ dramatically from the same pattern measured in the far field. In such cases the RCS engineer may resort to scale models illuminated at scale frequencies for their RCS determination. However, scale models can be challenging to fabricate because certain target characteristics, e.g., skin impedance, may be difficult to scale to shorter wavelengths. Such problems have led Burnside (*Abs. 1987 URSI Radio Sci. Meet.*, Blacksburg) and others to build compact ranges in which optical-type elements flatten the incident and scattered fields, and sophisticated apodization techniques suppress edge scattering. Although impressive with meter-size targets, compact ranges become technically challenging (and very costly) when designed to measure RCS patterns for larger targets (10-100 m).

Antenna designers, like RCS engineers, must deal with near-field effects when measuring the gain patterns for their antennas. Although compact ranges are widely employed, algorithmic methods are also used to solve the *near-field antenna problem*. Antenna specialists have vigorously pursued the problem for some years and can now report remarkable progress in estimating far-field gain patterns with near-field data (Yaghjian, *IEEE* AP-34(1), 1986).

The *near-field RCS problem* is more complex than the near-field antenna problem because the target's scattering pattern depends on the electromagnetic field that illuminates it. With respect to this problem, Joy (*Proc. 1985 AMTA RCS Meas. Tech. Work.*) has measured the monostatic near-field scattering pattern for a square plate, corrected for probe errors, and then compared the corrected near-field patterns with those predicted with a modal expansion. Edwards *et al.* (*Dig. 1974 Int. IEEE AP-S Symp.*) have reported similar results with respect to bistatic measurements on a square plate. In addition, Dinallo (*Proc. 1984 AMTA Meet.*) has used Kern's (*NBS Monograph 162*, 1981) plane-wave scattering matrix to develop an algorithmic procedure for inferring the far-field RCS pattern from near-field scattering measurements. Hallidy, et al. (*Abs. 1986 URSI Radio Sci. Meet.*, Philadelphia) have written a computer model that simulates the Dinallo procedure. Finally, Falconer (*Abs. 1987 URSI Radio Sci. Meet.*, Blacksburg) has successfully estimated the far-zone RCS pattern for an aluminum cylinder by applying the optical model to monostatic measurements of this target's near-field scattering pattern.

AN OVERVIEW OF NEAR-FIELD ANTENNA MEASUREMENTS

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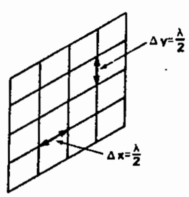
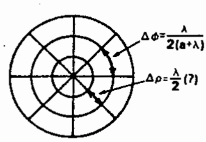
The development of near-field antenna measurements over the past twenty years seems to have anticipated the advent of specially designed antennas not well suited to measurement on conventional far-field ranges. During the first ten years of development, near-field antenna measurements were confined to government and university laboratories. The last ten years have seen a much wider interest that includes private industry, as the appeal and sometimes necessity of near-field techniques for measuring certain antennas becomes apparent.

After a brief history of near-field antenna measurements with and without probe correction, the theory of near-field antenna measurements is outlined beginning with ideal probes scanning on arbitrary surfaces and ending with arbitrary probes scanning on planar, cylindrical, and spherical surfaces. Probe correction is introduced for all three measurement geometries as a slight modification to the ideal probe expressions. Sampling theorems are applied to determine the required data-point spacing, and efficient computational methods along with their computer run times are discussed. The major sources of experimental error defining the accuracy of typical planar near-field measurement facilities are reviewed, and present limitations of planar, cylindrical, and spherical near-field scanning are identified.



PLANE-RECTANGULAR



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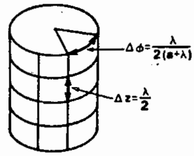
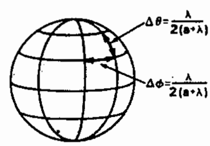


CYLINDRICAL



SPHERICAL

RCS MEASUREMENTS USING COMPACT RANGE

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About ten years ago, Scientific-Atlanta had the only compact range reflector system commercially available. It was approximately 14 feet square and had a test zone about 4 foot square. Since then, the compact range has been shown to be very useful, efficient and accurate for measuring the scattering properties of complex targets. As a result, there are several vendors of such systems today which claim that they can measure targets 40 feet in extent. This technology has not matured yet, but it is anticipated that the techniques used for the present systems can be extended to handle targets that are 150 feet in extent. After all, large reflector systems have been used for many years in more adverse situations than an anechoic chamber.

Even if one could construct a very large measurement facility, it is doubtful that many will be built. Modern scattering measurements are done much more efficiently using scale models (where appropriate) or full scale mock-up sections that can be measured in moderately sized ranges. The scattering is then evaluated using signal processing techniques to isolate scattering centers. The scattering centers can then be found on a mock-up section or the full scale structure. The scattering centers introduced by the mock-up can be windowed out of the results. This approach is very efficient and cost effective; as a result, it is expected that it will be used more-and-more in the development of large structures with scattering performance requirements.

MEASURING RADAR CROSS SECTION IN THE NEAR-FIELD

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Radar cross sections (RCS) must be measured at large distance. We exclude here the special near-field methods. The distance (R) must be so large that different RCS contributions are added in the same ways as at infinite distance. This leads to the rule $R > 2D^2/\lambda$ if the target cross range is confined within $\pm D/2$ and a phase error of $\pi/4$ is tolerated. It is shown, however, that if the RCS is measured as a function of an angle and is low-pass filtered with a cutoff period of ϕ_c (radians), the distance requirement could be changed to $R > 4D\phi_c^{-1}(1 - \lambda/2\phi_c D)$. All RCS measurements at such distances give approximately the same result after low-pass filtering. We assume that a set of isotropic point scatterers accurately describes the target.

EXTRAPOLATION OF MEASURED DATA USING AN ADMITTANCE-MATRIX MODEL

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We have formulated an admittance matrix (AM) model of scattering targets to estimate bistatic, near, or far fields from measured RCS data. The wire basis functions of the moment method (MM) Numerical Electromagnetic Code (NEC) have been used to model simple targets by computing the admittance matrices from a set of scattering measurements instead of computing wire interactions directly. The monostatic or bistatic scattering of arbitrary bistatic, near or far fields can then be computed in the usual way using the AM model. In contrast to Dinallo (*Proc AMTA*, Oct 84, Atlanta, GA), we incorporate knowledge of the physical nature of the target to help define the AM model.

We have validated our AM model using NEC. Scattering data generated by NEC is used to solve for the admittance matrix of the AM model. The AM model is then used to estimate the target scattering amplitude at other distances or bistatic angles. These values are then compared to the NEC result. Several examples of connected, unconnected, and complex loaded wires will be presented.

The current version of the AM model is based on the NEC wire basis functions. However, other basis sets, e.g. patches, may be used to develop AM models. This possibility has important implications for the modelling of complex materials and shapes.

NEAR-FIELD RCS MEASUREMENT DEVELOPMENTS

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Current work in near-field radar cross-section (RCS) measurement at BDM is focused on extending conventional near-field antenna measurement mathematics and measurement protocols to measuring bistatic RCS. To date we have limited our approach to planar near-field measurements. In the context of planar mesurement, we have extended the plane wave scattering matrix theory to include probe-corrected three-antenna interactions in which the third antenna is the unknown scattering object which we wish to measure. Assuming simple interactions, the resulting reflection integral is solved by means of two sets of two-dimensional Fourier transforms. The sampled-data solution of the reflection integral is implemented as in classical near-field antenna measurements. Spatial and angular filtering techniques are applicable.

We are also investigating methods for reducing the amount of data required, reducing measurement time and data storage volume, exploring ultimate limitations of this technique for bistatic RCS measurement, exploring small-angle bistatic RCS issues, developing error analyses, studying oversampling and filtering, and defining tradeoffs between signal-to-noise ratio and data acquisition time.

Measurement Techniques for Determining Near-Zone and Far-Zone Bistatic RCS

B. J. Cown, C. E. Ryan, Jr., and J. J. H. Wang

EMED/ECSL/GTRI, Georgia Tech, Atlanta, Georgia 30332 USA

J. Ch. Bolomey

LSS-SUPELEC, Gif-Sur-Yvette, FRANCE

Previous work at Georgia Tech [1, 2] has established the validity of planar near-field measurements of bistatic and forward scattered electromagnetic fields. These techniques have been demonstrated for models of simple and complex geometries including flat plates, cylinders, aircraft models and ship mast models. These previous studies demonstrated the measurement techniques and developed the required mathematical operations which were incorporated into computer algorithms. It was demonstrated that fuze sensor response could be accurately calculated using near-field measured data.

At the time these previous measurements were being conducted, the primary limitations of near-field techniques to large scale targets were (1) the physical size of the required measurement apparatus, (2) the intolerably long measurement time required for mechanical scanning, and (3) the tremendous data processing burden. However, technical advances during the last several years have substantially ameliorated all three of these previous limiting factors. In particular, compact range illuminators and planar scanners capable of measuring targets in excess of 10 meters are now available. Rapid near-field scanning at electronic rates via either arrays of modulated scattering elements (the Modulated Scattering Technique or MST) or via "classical" arrays can be employed to achieve reasonable measurement times [3, 4]. The advent of modern supercomputers as well as dedicated mainframe computers and array processors evidently makes the data processing manageable even for targets on the order of 1,000 wavelengths.

1. J. L. Edwards, C. E. Ryan, Jr., W. M. Leach, Jr., and W. J. Storey, "Near-Zone Radar Cross-Section Technique Development," AGAL-TR-74-227, November 1974, Contract No. F33615-74-C-1188, Air Force Avionics Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433

2. C. E. Ryan, Jr. and E. E. Weaver, "Open mast Scattering Investigation," IEEE Transactions on Antenna and Propagation, Vol. AP-30, No. 4 July 1982, pp. 768-773

3. B. J. Cown, P. G. Friederich, J. F. Estrada, F. L. Cain, J. Ch. Bolomey, D. Picard, G. Fine, And M. Mostafavi, "Accuracy and Speed Characteristics of the Bistatic MST for Rapid Near-Field Antenna Measurements," 1987 IEEE AP-S International Symposium Digest, Vol. 1, pp. 174-178

4. B. J. Cown, C. E. Ryan, Jr., and J. J. H. Wang, "Potential Near-Field Measurment Techniques for Determining Near-Zone and Far-Zone Bistatic RCS," Proc. of 1988 AMTA Symposium, Seattle, Washington, Sep. 1988

EXTENSION OF A NOVEL SAMPLING THEOREM TO THE NEAR FIELD/FAR FIELD SCATTERING PROBLEM

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A novel sampling theorem has recently been described by Bucci and Franceschetti. The theorem predicts the spatially bandlimited nature on a sampling surface of an appropriately compensated field radiated by a compact current distribution. Test parameters may be chosen that allow sampling of the compensated field at rates below the uncompensated Nyquist rate.

An extension of this theorem is developed here for the near field/far field scattering problem. It is shown that an appropriately compensated near field form of the scattering matrix may be considered to be bandlimited. This permits the density of the near field source locations as well as the scattered field sample points to be reduced below the density required by the Nyquist criterion for determination of the uncompensated near field scattering matrix.

Simulations employing this theorem are presented for two dimensional scattering by a cylinder and by a flat strip. Results are given that quantitatively verify the bandlimits on the compensated near field scattering matrix. The actual near fields, reconstructed from the coarsely sampled, compensated fields, compared favorably with the uncompensated fields sampled at the Nyquist rate. The far field radar cross section calculated from the reconstructed near field scattering matrix was found to differ negligibly from its theoretically predicted value except near $\pm 90^{\circ}$.

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INVESTIGATION OF THE MINIMUM SAMPLE REGION REQUIRED TO PREDICT RCS FROM PLANAR SCAN NEAR-FIELD DATA

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The radar cross section of a scatterer can be determined from the Fourier transform of near-field data measured using a planar scan in three dimensions or a linear scan in two dimensions (M.A. Dinallo, Proc. AMTA, Oct. 2-4, 1984, San Diego, CA). If the primary contributions to the transform originate from a limited region of the scan plane, only a small amount of measured data may be required to predict the cross section for a particular set of transmitter and receiver directions. Using a generalized form of the Bucci and Franceschetti theorem (to appear in IEEE Trans. AP) and stationary phase arguments, the region of the sample plane producing the primary contribution to the cross section has been determined.

The near-field can be written as the product of a compensated field and a two-way propagation phase. Using the Fourier transform integral and stationary phase arguments, the area of the sample plane producing the principle contribution to the cross section can be deduced for each spatial frequency of the compensated near-field. The region of the sample plane required to predict the cross section only needs to be large enough to include the contributions from all the relevant spatial frequencies. The required region is bounded since the compensated near-field is effectively bandlimited, as shown by the form of the Bucci and Franceschetti theorem generalized to treat the scattering problem (W. Hallidy, et al., this session).

The analysis will be discussed in terms of the 2D problem and extentions to the 3D case summarized. Results of 2D numerical experiments which confirm the behavior and demonstrate the potential savings in measured data will be presented. A physical interpretation of the stationary phase arguments will be given to further illustrate the results. If the spatial structure of the near-field is thought of as a summation of fringe patterns, the stationary phase results can be interpreted in terms of diffraction of waves by fringe gratings.

Thursday AM

Joint AP-S, URSI-B Session 66

NUMERICAL METHODS

Chairmen: Z. Csendes, Carnegie Mellon University;
A. Murphy, DuPont Co.

Room: Sheraton Regency C *Time*: 8:25-12:00

8:30	**An Investigation of 3-D EM Scattering Problems Using The Finite Element Method** S. P. Castillo, New Mexico State University; A. F. Peterson, Electromagnetic Communication Laboratory	332
8:50	**An Exploration of the Capability of the Hybrid Finite Element Method for EM Scattering by Inhomogeneous Cylinders** J. Jin, V. V. Liepa, The University of Michigan	See AP-S Dig.
9:10	**The Use of Isoparametric Elements in the Numerical Analysis of Three-Dimensional Anisotropic Scatterers** R. D. Graglia, R. S. Zich, Politecnico di Torino; P. L. Uslenghi, University of Illinois at Chicago	333
9:30	**Hybrid Finite Element/Boundary Element Analysis of a Stripline Notch Array** J. D'Angelo, M. J. Povinelli, M. A. Palmo, General Electric Company	See AP-S Dig.
9:50	**Analysis of Finite Element Method with Vector Basis Functions** H. Z. Sun, X. Min, K. M. Chen, Michigan State University	335
10:10	**COFFEE BREAK**	
10:40	**The Treatment of Edge Singularities in the Full-Wave Finite Element Solution of Waveguiding Problems** Z. Pantic-Tanner, C. H. Chan, R. H. Mittra, University of Illinois	336
11:00	**Finite Element Analysis Of Wave Propagation In Lossy Inhomogeneous Anisotropic Dielectric Media Based On Variational Principles** S. Cvetkovic, University of Surrey; F. A. Fernandez, J. B. Davies, University College London	See AP-S Dig.
11:20	**Aperture Admittance Matrix by Finite Element Method For Scattering From a Cavity-Backed Aperture** S. Jeng, National Taiwan University	See AP-S Dig.
11:40	**Finite Element Solution of Unbounded Electromagnetic Field Problems** D. Feng, G. Wang, Wuhan University	See AP-S Dig.

AN INVESTIGATION OF 3-D EM SCATTERING PROBLEMS USING THE FINITE ELEMENT METHOD

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Andrew F. Peterson
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Urbana, IL 61801

Three-dimensional electromagnetic scattering problems are of great interest to engineers and researchers. However, numerical solutions for practical 3-D problems are not currently feasible with traditional integral equation approaches due to the large amount of computer storage and time needed for solution. A differential equation solution approach for electromagnetic scattering problems has the advantage of producing a sparse system of equations which can be solved in a fraction of the time of that for an equivalent full matrix solution. The limiting factor in any differential equation solution is the size of the solution domain which must be discretized.

In practice, the solution region is truncated at some finite distance away from the scatterer by an artificial boundary. Over the artificial boundary a radiating boundary condition is applied so that the boundary appears to the internal region to be infinite. The finite element method is then used to solve the internal problem.

The finite element method for 3-D electromagnetic scattering problems will be described along with a vector 3-D radiating boundary condition. A comparison of solution techniques will be given for solving the large sparse systems of equations resulting from the finite element procedure.

THE USE OF ISOPARAMETRIC ELEMENTS IN THE NUMERICAL ANALYSIS OF THREE-DIMENSIONAL ANISOTROPIC SCATTERERS

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Politecnico di Torino, Italy

P.L.E. Uslenghi*
Department of Electrical Engineering and Computer Science
University of Illinois at Chicago

Electromagnetic scattering from three-dimensional inhomogeneous anisotropic structures is considered, in the frequency domain. The scatterer is characterized by a complex electric susceptibility tensor which includes both anisotropic permittivity and anisotropic conductivity, and by a magnetic susceptibility tensor. Perfectly conducting scatterers coated by some anisotropic material are also considered, because of their application in certain types of radar absorbers.

The electric and magnetic fields inside the anisotropic material are solutions of two coupled vector integro-differential equations that are an extension of the ones previously given in Graglia and Uslenghi (IEEE Trans, AP-32, 1984, pp. 867-9; ibid. AP-35, 1987, pp. 225-32).

These equations involve integrals over the volume of the anisotropic material and principal value integrals over the air-anisotropic material and metal-anisotropic material interfaces, as well as over the anisotropic material-anisotropic material interfaces. This formulation is best suited for numerical analysis, since it permits easily to model inhomogeneous scatterers by means of piece-wise homogeneous subregions.

To analyze the scattering region, the volume of integration is approximated by use of iso-parametric curved elements with quadratic distorsion; the expansion functions on these elements are of second degree in the parent parameter space. Delta sampling is performed at the corner nodes of the elements to find the unknown fields in the scattering region. The use of parametric elements for the moment method solution of volume integral equations has been proposed recently (Graglia, IEEE Trans. AP, accepted), and in general it allows better description of the geometry under investigation, considerable reduction in the number of unknowns and more accurate results than other methods. A detailed discussion of the 3D application of parametric elements to the present scattering problem and the attained advantages is given.

Numerical results concerning the internal field values are given for scatterers of different shape and having different susceptibility tensors, including perfectly conducting scatterers coated by anisotropic materials. These results show that the method leads to a very good numerical fulfillment of interface boundary conditions. Far-field results obtained by integration of the surface fields are also shown.

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ANALYSIS OF FINITE ELEMENT METHOD WITH VECTOR BASIS FUNCTIONS

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X. Min and K. M. Chen
Department of Electrical Engineering & Systems Science
Michigan State University, East Lansing, MI 48824

Recently, a simple and efficient finite element procedure with two-dimensional vector basis functions defined on triangular surface patches (or three-dimensional vector basis functions on tetrahedral volume elements) has been used by many workers to solve the electric field integral equation (EFIE).

Usually an EFIE is formulated as $(I+K)\,J(r) = E^i(r),\ r \in G$ or $K\,J(r) = E^i(r)\ \ r \in G$, where I is an identity operator, K is an integral operator and G is a regular region of interest. $J(r)$ is the induced current by the incident electric field $E^i(r)$. Under the assumption that the homogeneous EFIE has only the trivial solution, $(I+K)$ and K have bounded inverses by the Theorem of Fredholm's Alternative. The EFIE is then solved numerically as following:

The substitution of a test function $\hat{J} = \sum_{n=1}^{N} I_n f_n$, where I_n's are N unknown coefficients and f_n's are N vector basis functions defined on the partitions of the region G, into the EFIE leads to :

$$ERR + E^i = T\,\hat{J}$$

where $T = I + K$ or $T = K$ and ERR is the resulting error. Forcing $< ERR, f_m > = 0$, ($m = 1, \cdots, N$) gives to a $N{\times}N$ system of linear equations:

$$< E^i, f_m > = < T\,\hat{J}, f_m > \qquad m = 1, \cdots, N$$

To simplify the computation of the coefficients, the operator T is approximated by the operator T_h which is consistent with T and depends on the partition of the region. If the size of the patches is sufficiently small, T_h inherits the properties of T where the estimation of $\| T_h^{-1} \|$ is available. Thus, the system of linear equations becomes:

$$V_m = < T_h\,\hat{J}, f_m > \qquad m = 1, \cdots, N \qquad\qquad \text{or } V = Z\,I$$

where $Z = [< T_h f_n, f_m >]$ is a $N{\times}N$ matrix, $I = [\,I_1, \cdots, I_N\,]^T$ is a set of unknown variables (coefficients), V=[$V_1, \cdots, V_N]^T$ and $V_m = < \hat{E}^i, f_m >$ which is approximation of $< E^i, f_m >$.

This analysis aims to answer following questions:

1) Is this procedure feasible or the matrix Z invertible?

2) How does the numerical solution converge? What is the error estimate?

3) As the patch size becomes small, $Z\,I = V$ may become ill-conditioned. What is the stability of the procedure?

THE TREATMENT OF EDGE SINGULARITIES IN THE FULL-WAVE FINITE ELEMENT SOLUTION OF WAVEGUIDING PROBLEMS

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The finite element method(FEM) is regarded as a powerful numerical technique for solving a variety of waveguide problems, because it is capable of handling waveguides of complicated cross-section and with arbitrary fillings of inhomogeneous media, be they isotropic or anisotropic. The use of high-order ordinary elements allow one to enhance the numerical accuracy of the solution without increasing the number of mesh points when the field inside the guide is well-behaved. However, many waveguiding structures contain conducting or dielectric edges embedded in an inhomogeneous isotropic or anisotropic medium, and the field behavior can be singular in the vicinity of these edges. If conventional, ordinary elements are used to model these rapidly varying fields , it becomes necessary to use a fine mesh near the edge regions and the reduction in mesh size has the effect of increasing the computational time as well as memory requirements. However, it has been shown that both for the quasi-static transmission line problems (Z. Pantic and R. Mittra, URSI Symp. Dig., 68, 1985; Z. Pantic and R.Mittra, T-MTT, 34, 1096-1103, 1986) as well as for the time-domain diffraction problems (S. Ray, URSI Symp. Dig., 247, 1986), the number of nodes necessary to model the fields can be significantly reduced by employing singular elements. While the ordinary elements represent the field components using polynomials, the singular elements are based on analytical solutions for the fields near the edges, and are designed to mimic the theoretically-predictable singular behavior of these fields as closely as possible. It is shown that it is possible to derive the elements of the FEM matrix involving the singular elements by carrying out the necessary integrations in a closed form. Furthermore, for certain singularity parameters, "singular" matrices are shown to have a form similar to those of ordinary FEM matrices.

In order to construct singular element basis functions, a prior knowledge of the singularity parameter governing the field behavior at the edges is required. For 2-D problems, a new transcendental equation for singularity parameter is given in this paper for an anisotropic medium described by an arbitrary permittivity and permeability tensors. For a conducting edge, the singularity is always present in the field components transverse to the edge. However, for a dielectric edge, the fields can be either singular or nonsingular depending upon the edge configuration and the parameters of the medium.

Numerical results for some typical waveguiding structures containing sharp edges are presented in the paper.

Thursday AM

URSI-F Session 68

POLARIMETRIC SCATTERING

Chairmen: W. Boerner, University of Illinois; J. J. van Zyl, JPL

Room: Sheraton Comstock B *Time*: 8:25-12:00

POLARIMETRIC MATCHED IMAGE FILTER FOR POL-SAR IMAGE INTERPRETATION OF OCEAN SURFACE SCATTER

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A statistical analysis of complete polarimetric SAR image data collected with the JPL/CV-990 L-band POL-SAR system is performed. Eight real numbers (complex elements of the 2x2 polariztion scattering matrix) are associated with each image pixel. A novel polarimetric matched imaged filtering approach is introduced which makes use only of polarimetric optimization methods, i.e., without the use of other standard image processing techniques. First, the optimal (maxima or minima of the scattered power) transmitted and received polarizations are found for each image pixel and then the results are analyzed statistically via a set of joint bivariate histograms of the eigenvectors. Finally, the image response to the optimal antenna polarization is simulated digitally via the receiver polarization adjustment in accordance with relevant histogram peaks. The resulting polarimetric matched image filtering process is then applied to ocean clutter removal for a particular JPL/CV-990 POL-SAR data set collected over the San Francisco Bay area. The corresponding set of optimized images are of rather high quality providing very encouraging results.

STATISTICAL ANALYSES AND SOME POLARIMETRIC SIGNATURES OF POL-SAR IMAGES

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Department of Electrical Engineering & Computer Science
University of Illinois at Chicago, Chicago, IL 60680-4348

We have performed statistical analyses of complete polarimetric SAR image data obtained with the JPL/CV-990 L-band POL-SAR system on the San Francisco Bay area. Here, we report on some promising preliminary results concerning deviations of amplitude (one-look) images from Rayleigh statistics depending on the terrain type (roughness) and the nature of the polarimetric scattering.

Furthermore, we identify and interpret the behaviour of some important polarimetric functions of the scattering matrix versus the terrain texture, e.g., double bounce/corner reflector behaviour of the urban area section of the image. Some physical models describing the observed effects are provided.

THE OPTIMAL POLARIZATIONS FOR ACHIEVING MAXIMUM CONTRAST IN RADAR POLARIMETRY

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and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

There is a considerable interest in determining the optimal polarizations that achieve maximum contrast between two scattering classes in radar polarimetric images for the purpose of terrain discrimination. In this paper, we present a systematic approach for obtaining the optimal polarimetric matched filter which produces maximum contrast between two scattering classes, each represented by its respective covariance matrix.

To accomplish this, we derive a linear weighting vector that maximizes the expected power return ratio, i.e., the contrast ratio between the two scattering classes. The maximization procedure involves solving an eigenvalue problem where the eigenvector yielding this maxima will correspond to the optimal polarimetric matched filter. Then, through use of polarization synthesis, it is demonstrated that when this weighting vector is utilized to process fully polarimetric radar images, the maximum contrast between the two respective classes results. The sub-optimal problem of a fixed transmitting polarization is also considered. In this case, the received polarization is optimized such that a maxima in the contrast ratio is obtained under this constraint. To exhibit the physical significance of this filter, we transform it into its associated transmitting and receiving polarizations, in terms of their horizontal and vertical vector components.

This technique is then applied to radar polarimetry obtained from the Jet Propulsion Laboratory. It is shown, both numerically and through the use of radar imagery, that maximum image contrast can be realized when data is processed with the optimal polarimetric matched filter.

This work was sponsored by the Defense Advanced Research Projects Agency. The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Government.

CLASSIFICATION OF EARTH TERRAIN USING POLARIMETRIC SYNTHETIC APERTURE RADAR IMAGERY

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Supervised and unsupervised classification procedures are developed and applied to synthetic aperture radar (SAR) polarimetric images in order to identify its various earth terrain components. For the supervised classification processing, the Bayes technique is utilized to classify fully polarimetric and normalized polarimetric SAR data. Simpler polarimetric discriminates, such as the unnormalized and normalized magnitude response of the individual receiver channel returns, in addition to the phase difference between the receiver channels are also considered. Covariance matrices are computed for each terrain class from selected portions within the image where ground truth is available, under the assumption that the polarimetric data has a multivariate Gaussian distribution. These matrices are used to train the optimal classifier, which in turn is used to classify the entire image. In this case, classification is based on determining the *distances* between the training classes and the observed feature vector, then assigning the feature vector to belong to that training class for which the distance was minimum. Another processing algorithm based on comparing general properties of the Stokes parameters of the scattered wave to that of simple scattering models is also discussed. This algorithm, which is an unsupervised technique, classifies terrain elements based on the relationship between the orientation angle and handedness, or ellipticity, of the transmitted and received polarization state. These classification procedures will be applied to San Francisco Bay and Traverse City SAR imagery, supplied by the Jet Propulsion Laboratory. It is shown that fully polarimetric classification yields the best overall performance. Also, in some selected areas where the observed amplitudes of the returns are quite different than that of the training data, classification techniques not based on the absolute amplitudes of the returns, e.g., the normalized polarimetric classifier, produced a more consistent result with respect to the ground truth data.

GENERATION OF A 4X4 MUELLER MATRIX FROM A 2X2 SCATTERING MATRIX TIME SERIES

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The polarization state of the scattered wave resulting from the interaction of the incident wave and the radar target system depends on the target's scattering matrix which is a function of: (1) the frequency of the incident wave; (2) the radar target under study; (3) the orientation of the target with respect to the incident wave vector; (4) the azimuthal orientation of the incident wave and the reflected wave propagation directions relative to the reference coordinate axes; (5) the relative transmitter/receiver, bistatic or monostatic mode of operation; and (6) the fluctuation of scattering centers on the target. When a time-dependent scatterer is illuminated by a monochromatic (completely polarized) wave, the amplitude and the phase of the reflected (scattered) wave are functions of time. The scattered wave is non-monochromatic and, therefore, partially polarized. Consider a quasi-monochromatic reflected wave at a fixed point in space represented by the Jones vector:

$$\bar{E}(t) = \{|E_x|(t)\exp(i\delta_x)\hat{a}_x+|E_y|(t)\exp(i\delta_y)\hat{a}_y\}$$
$$= \{A(t)\hat{a}_x+B(t)\exp[i\phi(t)]\hat{a}_y\}\exp(i\omega t)$$

where the time dependence of $A(t)$, $B(t)$, and $\phi(t)$ causes a spectral spread Δf such that $\Delta f << \omega/(2\pi)$. If this wave is being measured and the measurement time duration τ satisfies $\tau << (2\pi)/\Delta f$, then the wave can be considered to be completely polarized. This indicates that the measurement time is so fast that the time-dependent fluctuating target may be considered frozen in time (snapshot). But, if the measurement time τ is such that $\tau >> (2\pi)/\Delta f$ (i.e., long averaging times), the wave must be considered to be partially polarized. In the first case, the wave can be completely represented by a 2x1 Jones vector and characterized by a 2x2 scattering matrix. In the latter case, the representation by a Jones vector is not possible and the target cannot be effectively characterized by a scattering matrix, [S]; but, a 4x1 Stokes vector formulation together with the 4x4 Stokes reflection matrix representation [M] is most appropriate. This paper will review the characteristics of the 2x2 scattering matrix, [S], which will be designated as the Jones matrix, and the 4x4 scattering matrix, [M] referred to as the Mueller matrix; and the relationship(s) between the two will be established by the detailed general deviation of the Mueller matrix from the Jones matrix, using time series ensemble averaging. The physical realizability of these scattering matrices will then be reviewed; and the necessary and sufficient conditions for the Mueller matrix to be derivable from a 2x2 Jones matrix will be established.

K-DISTRIBUTION AND POLARIMETRIC TERRAIN RADAR CLUTTER

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A generalized K-distribution is proposed to model the statistics of the fully polarimetric returns from the terrain cover. In the past, K-distribution has been used successfully to characterize the intensity distribution of single polarization returns. Recently, fully polarimetric synthetic aperture radar (SAR) data with polarizations HH, HV, and VV have been proven useful in remote sensing of earth terrain and in this paper we generalize the K-distribution to model fully polarimetric terrain radar clutter. The generalized K-distribution is a better description of the statistics of the SAR polarimetric data than the Gaussian distribution and would be useful in identification and classification of terrain types in the SAR polarimetric data.

In general, all polarization returns of each single polarimetric measurement are correlated with different variances. Therefore, we assume an n-dimensional anisotropic random walk model where the coordinate components of each step are characterized by a covariance matrix and the number of steps or scatterers is of negative binomial distribution with parameter α. The anisotropy in the model refers to the fact that the the covariance matrix is not proportional to an identity matrix. A generalized K-distribution for polarimetric data is derived when the average number of steps approaches to infinity. The K-distribution is also generalized to the non-zero mean case, which can be used to model the statistics of transmitted electromagnetic wave through atmosphere. It is found that if a zero-mean K-distributed random vector is normalized by its Euclidean norm, the joint probability distribution of the normalized quantities is independent of the parameter α and is the same as that derived from a zero-mean Gaussian-distributed random vector. The results are illustrated by analyzing the normalized intensity moments of the polarimetric SAR images provided by the Jet Propulsion Laboratory and comparing them with the generalized K-distributed polarimetric model.

POLARIZATION CONSIDERATIONS IN SCATTERING FROM ROUGH SURFACES

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In an earlier paper (Raemer and Preis, Vol. EMC-22, No. 1, February 1980) the authors investigated the issue of apparent cross-polarized radar returns predicted by first-order theory of scattering from a rough surface. The numerical results presented were for a horizontal mean surface on which are superposed small-scale random fluctuations. First order theory does not predict crosspolarized returns when polarization is defined with respect to the mean scattering surface. However, the polarization as observed by the receiving antenna is better defined with respect to its aperture plane, since the antenna has no way of separating out different polarizations with respect to the scattering surface if that surface is not perfectly flat. The earlier results alluded to above show corresponding returns with respect to antenna aperture that are about 40dB below the corresponding copol returns for perfectly horizontal mean surfaces.

Recent investigations of this problem have extended the analysis to include large scale surface roughness and the effects of the antenna pattern. Elliptical polarization is also included in this work. The extensions of the theory are discussed and some numerical results are presented on which the cross polarized returns are shown to be more pronounced when these additional results are introduced.

POLARIMETRIC ISAR IMAGING USING EITHER MEASURED OR CALCULATED TRANSIENT SIGNATURES

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The Ohio State University ElectroScience Laboratory
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An approach to generate synthetic target images from electromagnetic scattering data is described. A substitute algorithm which uses one dimensional (1-D) filtered time domain signals together with aspect information is used to replace the conventional 2-D Fourier transform. Polarimetric scattering characteristics of the targets of interest are investigated. Images of the same target with different linear polarizations are generated and compared. Different sets of colors are assigned to different polarizations to illustrate the polarization dependence of the images. Frequency scaling techniques are applied to combine measured data on different scale models to widen the bandwidth. The work has concentrated both on geometrically simple and more complicated targets. Polarization is shown to be a useful tool for target identification.

EXPERIMENTAL DETERMINATION OF SCATTERING FROM E-POL AND H-POL SLIT CYLINDERS

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Assessing the exact electromagnetic field structure within and around a hollow or concentric cylinder with an axial slit is a complex task of great practical importance. Much of the previous work in this area has focused on a method of moments solution which does not explicitly take edge effects into account.

Recent developments in both theoretical and experimental methods for viewing cross-sectional electric fields in slit cylinders lend themselves to examination and subsequent comparison. Experimental techniques developed at the University of Colorado are based on infrared (IR) measurements of Joule heating induced when electromagnetic energy is absorbed by lossy dielectric materials. The surface temperature patterns correspond to the field intensities in the surface. An infrared scanning system detects the thermal radiation and the actual field strengths are then related to the surface temperature variations. The detection screen material is of planar construction and thus provides a two-dimensional field mapping. By moving the screen along the axis of the cylinder the three dimensional field is obtained.

The data received from this scanning system is graphically depicted by a thermogram, on a pixel by pixel basis, or by equal contours, the intensity of the field distribution. These results can be compared with contour maps of the electric field generated by a theoretical technique (R. W. Ziolkowski and J. B. Grant, IEEE Transactions of Antennas and Propagation. AP-35, 504-528, 1987). This technique is based on the generalized dual series solution which yields more precise edge effects (W. A. Johnson and R. W. Ziolkowski, Radio Sci. 19, 275-291, 1984).

Comparisons will be made between the theoretical and experimental approaches for various slit cylinder configurations, including E-pol and H-pol alignments, varying slot sizes, concentric cylinders, and varying frequencies from 1 to 18 GHz.

+Affiliated with F. J. Seiler Research Laboratory, U. S. Air Force Academy, Colorado Springs, CO 80840

Thursday AM

Joint AP-S, URSI-B Session 70

RADIATION FROM WAVEGUIDES

Chairmen: R. Scharstein, Sensis Corporation;
S. Lakshamanaswamy, University of Rhode Island

Room: Schine 304C *Time*: 8:25-12:00

8:30	**A Method Of Moments Analysis Of A Dual Frequency Rectangular Waveguide-Ridged Waveguide Cavity Antenna** J. M. Jarem, The University of Alabama In Huntsville	See AP-S Dig.
8:50	**Rectangular Waveguide Loaded By A Radiating Slot** M. Kisliuk, A. Axelrod, MWA/Microwave Antennas Ltd.	See AP-S Dig.
9:10	**Reflections In Open-Ended Elliptical Waveguide With An Infinite Flange** T. S. Bird, CSIRO	See AP-S Dig.
9:30	**Broad Wall Tilted Slots on Rectangular Waveguides** S. Rengarajan, University of California, Los Angeles	See AP-S Dig.
9:50	**Dielectric-Covered Waveguide Longitudinal Slots** P. B. Katehi, University of Michigan	See AP-S Dig.
10:10	**COFFEE BREAK**	
10:40	**Electromagnetic Directed Energy Pulse Trains Launched by an Open, Semi-Infinite, Circular Waveguide** I. M. Besieris, A. Shaarawi, Virginia Tech.; R. W. Ziolkowski, Lawrence Livermore National Laboratory	348
11:00	**Fast Analysis of Multimode Corrugated Conical Horns** J. Molina, M. Calvo, Universidad Politecnica de Madrid	349
11:20	**Minimisation of Pulse Distortion in a Long Slotted Waveguide Antenna** B. K. Sarkar, R. Roy, C. J. Reddy, TIFR	See AP-S Dig.
11:40	**Radiating Properties Of Sectionalized Uniform Helical Structures** Z. Ying, China Academy of Post & Telecommunication Science	See AP-S Dig.

ELECTROMAGNETIC DIRECTED ENERGY PULSE TRAINS LAUNCHED BY AN OPEN, SEMI-INFINITE, CIRCULAR WAVEGUIDE

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A new decomposition of exact solutions to the scalar wave equation into bidirectional backward and forward travelling plane waves is described. These elementary blocks constitute a natural basis for synthesizing Brittingham-like solutions with unusually slow energy decay characteristics. Examples of such solutions, besides Brittingham's original modes [J. Appl. Phys. 54, 1179 (1983)], are Ziolkowski's EDEPT [URSI General Assembly, Tel Aviv, Israel, 1987] and Hillion's spinor modes [J. Math. Phys. 28, 1743 (1987)]. A common feature of these solutions is the incorporation of certain parameters that can be tuned in order to achieve slow energy decay patterns.

It is our aim in this exposition to show that the aforementioned decomposition can be used to solve Cauchy initial-boundary problems. A specific demonstration will be given in connection with a semi-infinite circular waveguide excited by a localized initial pulse whose size is related directly to parameters similar to those arising in Ziolkowski's EDEPT solutions. The far fields are computed using Kirchhoff's integral formula with a time-retarded Green's function. The resulting approximate solutions are causal, have finite energy and exhibit a slow decay behavior. Like the EDEPT, these approximate far field solutions contain certain parameters that can be adjusted to control the shape of the pulses as they propagate in free space. In this case, however, these parameters are linked to physically meaningful quantities, such as the size of the initial pulse, the cross sectional area of the waveguide and its cutoff frequencies. A major conclusion arising from our preliminary investigation is that the decay of the wave trains is slowed down significantly by using larger initial pulses and exciting mostly higher order modes in the waveguide.

FAST ANALYSIS OF MULTIMODE CORRUGATED CONICAL HORNS

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Several approximations to the aperture field distribution of corrugated conical horns have been proposed in order to reduce the evaluation complexity due to the spherical functions. The present paper deals with the approximation, first suggested at [Narasimhan, Rao. "Hybrid Modes in Corrugated Conical Horns". Elect. Lett. Jan. 1970], obtained by substitution of $\sin\theta$ by θ in the characteristic wave equation and subsequent resolution of the resulting Bessel differential equation. In this way, the complicated formulation of the modes propagating along the corrugated conical horn is reduced to a radial dependence on the Bessel functions, an ordinary azimuthal dependence and a correcting phase term including the spherical form of phase fronts.

The radiated field is obtained by means of Bessel-Zernike (BZ) Series Expansion of the aperture fields, which enables a quick evaluation of the radiation vector as a function of the expansion coefficients and the direction. This scheme was successfully applied [Calvo, Molina, Lois. "Fast Analysis of Multimode Conical Horns by Bessel-Jacobi Series Method". 2ª Simp. Elect. Telec. Lisboa, May 1986] finding out several advantages that also appear in the present application. The critical point of BZ method is the evaluation of coefficients. Making the polar coordinate ρ=at, aperture fields can be expressed as:

$$E_t = A_{mn}\ J_{m\pm1}(S_{m\pm1,n}\ t)\ \exp(-j\ \pi(at)^2\ /(\lambda L))\ \exp(jm\phi)\ (\hat{\theta} \pm j\ \hat{\phi}) \quad (1)$$

$\hat{\theta}$ $\hat{\phi}$ being the spherical unity vectors, ρ ϕ polar coordinates of aperture points, $J_v(x)$ bessel functions, $S_{v,n}$ the n-th root of $J_v(x)$, (upper / lower sign for HE_{mn} / EH_{mn} modes), a the aperture radius and L the horn length.

It is obvious in (1) that the aperture field distribution can be separated in a mode-dependent factor, which can be precalculated and stored for further calculations, and a geometry-dependent factor which should be calculated for any particular analysis.

This scheme was implemented in a computer program and results compare very well with other authors' former works. Conclusions on practical examples and validity range of the approximation will be presented.

Notes

Thursday AM

Joint AP-S, URSI-E Session 71

RADIO WAVE PROPAGATION

Chairmen: J. Wait, University of Arizona;
C. E. Eftimiu, McDonnell Douglas

Room: Newhouse A1 *Time*: 8:25-12:00

8:30	**Propagation Limitations in Determining Lightning Source Parameters from Remote Locations** J. R. Wait, P. Teschan, F. Assi, University of Arizona	352
8:50	**Improved Meteor Burst Channel Model for a High-Thruput Communication System** A. K. Gupta, J. R. Herman, GTE	353
9:10	**Comments on the "Head Model"** A. Schneider, CyberCom Corporation	See AP-S Dig.
9:30	**Propagation Characteristics of Low Base-Station Antennas on Urban Road** S. Kozono, A. Taguchi, NTT Radio Communications Systems Laboratories	See AP-S Dig.
9:50	**Propagation Studies on Smooth-Earth Diffraction Path** R. K. Tewari, B. S. Jassal, Defence Electronics Applications Laboratory; M. N. Roy, Jadavpur University	See AP-S Dig.
10:10	**COFFEE BREAK**	
10:40	**On The Concept Of Optimal Polarizations In Problems of Radio Wave Propagation** A. P. Agrawal, W. Boerner, University of Illinois at Chicago	See AP-S Dig.
11:00	**Modelling the Spatial Large Scale Statistical Dependence of Rain** F. Barbaliscia, Fondazione Ugo Bordoni; G. Brussaard, Estec - Noordwijk - Holland; A. Paraboni, Politecnico di Milano	See AP-S Dig.
11:20	**Spatial Statistical Dependence of Rainy Events** F. Barbaliscia, Fondazione Ugo Bordoni; G. Brussaard, Estec; A. Paraboni, Politecnico di Milano	See AP-S Dig.
11:40	**Depolarization Due To Raindrops And Ice Particles Along Ka-Band Satellite Communication Path** Y. Maekawa, N. S. Chang, A. Miyazaki, Osaka Electro-Communication University; T. Segawa, CSK Corporation	See AP-S Dig.

PROPAGATION LIMITATIONS IN DETERMINING LIGHTNING SOURCE PARAMETERS FROM REMOTE LOCATIONS

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For many years the lightning community have observed electromagnetic fields at points remote from the discharge. The usual procedure is to interpret the recorded waveforms in terms of assumed source models. While there is no doubt that much valuable insight into the phenomenolgy has been obtained, we feel that direct inversion of the observed data might be possible if the forward electromagnetic problem is fully understood.Thus the first part of this paper will be to review various published papers that deal with the propagation influences that can modify the received signal characteristics.Effects of finite ground conductivity,earth curvature, topography,antenna siting, and local environment are all important .We illustrate some of these problems using specific examples where viable calculations can be made.(J.R.Wait,Proc.IEEE, 74,1173-1181,1986)

In the second part of the paper,several direct inversion schemes are are described using fairly idealized situations. For example we show that the time dependent dipole moment of a vertical discharge column can be deduced directly from the recorded electric and magnetic field waveforms at a distant observation sight.Propagation influences can be built into the scheme at a cost of non-simple data processing.

The desirability of making field waveform measurements simultaneously at two or more remote locations is stressed. (A.G.Jean,W,L.Taylor and J.R.Wait, J.Geophys.Res.65 ,907-912, 1960 ; Y.T.Lin, M.A.Uman, J.A. Tiller,R.D. Brantley,W.H. Beasley, E.P. Krider and C.D. Weidman,J.Geophys.Res. 84,6307-6314,1979). Only in this way can we untangle the usually unknown propagation influences from the source characteristics which we are trying to determine.Also we make a plea to experimentalists to record and publish all relevant information connected with the data gathering such as antenna characteristics, ground conductivity, surface features such as coast lines, and equipment frequency response.

Submitted to 1988 URSI Meeting,Syracuse Univ. (Comm.E Preference)

IMPROVED METEOR BURST CHANNEL MODEL FOR A HIGH-THRUPUT COMMUNICATION SYSTEM

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This paper discusses an improved meteor burst channel model in terms of Rician channel rather than currently used Rayleigh model in a high thruput meteor burst communication system (A. K. Gupta and J. R. Herman, "A Channel Adaptive High Thruput Meteor Scatter Communication System," National Radio Science Meeting, abstract, Boulder, CO, Jan. 1988). The ratio of the specular component power to the diffuse component power is obtained by multiplying the ratio of number of returns from overdense trails to that from underdense trails and the ratio of received power from corresponding trails. The time dependence of total power can be obtained by combining the power equations of underdense and overdense trails in proportional to the corresponding number of trails above a threshold.

The modified equation for the waiting time interval for the Rician channel is obtained from the inverse of total meteor occurrence rate obtained by Hines. A simplified model for the generalized waiting-time calculations is also provided in this paper. The capacity formulation for high thruput communication via Rician channel will be different to Dr. E. J. Baghdady's proposal in 1979 for a high data rate system utilizing Rayleigh model (A. K. Gupta and M. D. Grossi, Proc. of Ionospheric Effects Symposium, Alexandria, VA, 282-296, 1981).

Notes

Thursday AM

URSI-B Session 73

NUMERICAL TECHNIQUES FOR EM PROBLEMS

Chairmen: E. Arvas, Syracuse University; W. Whitehead, DuPont Co.

Room: Newhouse 254 *Time*: 8:25-12:00

FAST-FREQUENCY STEPPING WITH LS-DECOMPOSITION

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Techniques for accelerating the computation of the impedance matrix, Z, in moment method solutions are presented. LS-decomposition, where

$$Z = jwL + (1/jw)S + Z_f,$$

enables separate and independent procedures to be used in computing static and harmonic terms. Static integration, which often requires the use of high-resolution numerical integration, is thereby restricted to use in filling the L and S matrices which are stored for rapid insertion during frequency scanning. Harmonic integrals, which comprise the Z_f matrix, are computed efficiently at each frequency using three geometric parameters per antenna segment which are computed only once as a by-product of the computation of L and S. For high-performance computers with parallel processing, the decomposition of the matrix filling process offers access to a new level of speed. This acceleration of response is very important for users exploring complicated antenna interactions in congested siting studies on ships, vehicles, and airframes.

Further acceleration for swept frequency applications is also considered through the use of matrix solution techniques using the stored inverses of L and S. This avoids redundant computation and offers potential advantages in the use of real arithmetic on the poorly-conditioned S matrix. Related techniques for improving the stability in regions near anti-resonance are also discussed.

NUMERICAL FIELD CALCULATION WITH MMP-PROGRAMS ON PC's

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The MMP-method is a very powerful instrument for the calculation of electromagnetic fields in piecewise linear, homogeneous, isotropic domains. Since MMP-expansions solve field equations in every region analytically, only the discretisation of the boundaries is necessary. This allows to describe the geometry of a given problem in a quite simple way. Furthermore relatively small and compact matrices (typically 100 columns) are obtained, which may be solved with fast updating routines. These advantages allow the implementation of MMP-programs even on small computers.

At present two MMP-programs for the calculation of static fields and time-harmonic (E-, H-, EH-, HE-) waves on cylindrical structures exist. The first one neglects losses to save memory and computation time. The second one works fully with complex numbers and allows the calculation of guided waves as well as scattering problems. Both of them are written in FORTRAN and make use of the zooming capability of the MMP-method for the graphic output.

The programs have been implemented on very different machines (PC's, workstations, mainframes) with different compilers and were already used to solve a lot of typical problems. Reasonably small execution times are obtained on the entire PC family of IBM and compatibles if a math co-processor is installed. A comparison of compilers and machines is also given.

AUTOMATIC CHOICE OF MMP-FUNCTIONS IN DYNAMIC PROBLEMS

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The MMP-method (Multiple Multipole-method) has been successfully applied for solving problems in electrodynamics as well as in optics. It is a so called semi-analytical technique, since the solutions fulfill the differential equations exactly, where the boundary conditions are fulfilled approximately by numerical procedures (usually least squares techniques). The basic concept of the MMP-method, the expansion of the unknown field functions in series in several subdomains seperately, and the use of non-orthogonal expansion functions leaves a lot of freedom to the user, but forces him to know deeply the mechanism of the technique.

To avoid the difficulties which may arise in choosing the expansion functions, an automated procedure is now available to find enough functions for almost any technical problem. The new procedure was applied to statics first and has now also been applied to dynamical problems, scattering problems as well as eigenvalue problems (e.g. wave guides).

The "pole-finding-procedure" (the expansion functions are so-called *multipoles*) is split into two steps. In a first step, a basic set of functions is produced very straightforwardly using only geometrical criteria. In many cases, the results obtained by this basic set of functions fulfill practical requirements. Hence, there is no need to perform the second step. For those cases, where a higher accuracy is requested, the procedure searches for additional functions, which are optimally predestinated to minimize the error of the first approximation obtained using only the basic set. Therefore, it is possible to decrease the error iteratively.

Results will be presented which leave no doubt as to the accuracy and the computational amount. The program runs on PC as well as on work stations or bigger computers.

A TRANSVERSE APERTURE-INTEGRAL-EQUATION SOLUTION FOR EDGE DIFFRACTION BY MULTIPLE LAYERS OF HOMOGENEOUS MATERIAL

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The authors have recently proposed a numerical method for the computation of diffraction coefficients at the truncation of semi-infinite stratified structures ("A Transverse Aperture-Integral-Equation Method for Numerical Evaluation of Edge Diffraction by Semi-Infinite Structures, National Radio Science Meeting, Boulder, CO, January, 1987.) This method has the potential to provide a means of computation of diffraction coefficients from a broad class of material profiles, including sheet-anisotropy models for conducting composites.

In this presentation we concentrate on the application of this method when the material profile comprises layers of homogeneous, potentially lossy material. In our earlier presentation we discussed the example of classical half-plane diffraction. The method was shown to allow analytical evaluation of the distant magnetic fields in an infinite aperture, thereby limiting the domain on which the unknown was significant to a modest extent--specifically ±2-3 wavelengths from the edge. When the diffracting sheet comprises penetrable material, the solution domain must be segmented into subdomains spanning the individual material faces.

The presence of material layers provides a better measure of the computational complexity of the method, because one must deal with Green's functions that are expressed as Sommerfeld-type integrals. The impact of these spectral integrals is twofold. The first is that the elements constituting the moment matrix must be computed as Sommerfeld integrals. The second is that the asymptotic anticipation involves reflection coefficients that are angularly dependent and is therefore more complicated. The computation issues that arise are discussed and illustrative computations are presented.

CALCULATION OF THE FRESNEL TRANSITION FUNCTION OF COMPLEX ARGUMENT FOR THE METHOD OF STEEPEST DESCENTS

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The Fresnel transition function F(z) arises in many types of diffraction problems in which the method of steepest descents is utilized. For perfectly conducting wedge diffraction, the Fresnel function of real argument is required and efficient means for calculating this function are available. For imperfectly conducting problems involving surface impedance boundary conditions, the Fresnel function of complex argument z is encountered. For complex argument, the Fresnel function is more difficult to calculate and the choice of an appropriate branch cut for the transition function becomes important.

Many large computer systems have mathematical software packages which have some form of a complex error function and the Fresnel transition function can be related to the error function. Care must be taken to assure a branch cut of the square root of the complex argument z will lie along arg $z=\pi/2$. This keeps $\sqrt{z}$ below the Stokes lines so that $-3\pi/4<\arg\sqrt{z}<\pi/4$. The discontinuity over the branch cut is important to provide the proper discontinuity in a steepest descent asymptotic solution to account for a pole crossing a steepest descent path.

Smaller computers or hand calculators will generally not have access to a complex error function and other means of calculation are sought. A small argument asymptotic form of the Fresnel transition function exists and its accuracy depends on the number of terms chosen and on the location of the argument in the complex plane. This small term form also includes a square root term for which an appropriate branch cut must be identified.

For large arguments, an asymptotic expansion is available. The asymptotic expansion is not necessarily convergent; however good accuracy can be obtained by choosing an appropriate number of terms in the series. The series is truncated before the term of smallest magnitude to minimize the resultant error. Indeed for best accuracy, fewer terms should be included for small arguments. This is in sharp contrast to the small argument form in which more terms always provide better accuracy.

The intermediate ranges are effectively covered with good accuracy when up to 20 terms in the small and large argument series are considered. An alternate approach is to perform a numerical integration for an intermediate range argument. Comparisons of the errors of the various methods and the computer time requirements will be discussed in the presentation along with formulations for determining the branch cuts and associated discontinuities.

EIGENVALUE PROJECTION THEORY APPLIED TO THE NUMERICAL SOLUTION OF INTEGRAL AND DIFFERENTIAL EQUATIONS

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One aspect of the numerical analysis of electromagnetic field problems involves the eigenvalue character of the associated matrix equations. Recent work suggests that significant insight can be obtained from the matrix eigenvalue spectrum, via a theory that relates the matrix spectrum to the spectrum of the continuous operator equation and the specific discretization used to construct the matrix equation (A. F. Peterson, "Eigenvalue projection theory for linear operator equations of electromagnetics," UILU-ENG-87-2252, University of Illinois, Urbana, IL, 1987).

Knowledge of the eigenvalues of the continuous and matrix operators can aid in the selection of a robust formulation and discretization procedure. For example, the eigenvalue spectrum of the electric and magnetic field integral operators often used to represent conducting scatterers are very different in character. The behavior of the equations for low-frequency scattering is apparent from the spectrum, and helps explain the difficulty in solving the EFIE numerically at low frequencies. The eigenvalue spectrum can also characterize the stability of these equations for large numbers of unknowns. As a third application, eigenvalue projection theory demonstrates the dependence of the matrix spectrum on the basis and testing functions used within the method-of-moments discretization, and can explain the ill-conditioning sometimes encountered as a result of using entire-domain basis and testing functions.

The selection of an appropriate solution algorithm can also be enhanced by knowledge of the matrix eigenvalue spectrum. It is well known that the convergence characteristics of iterative algorithms depend on the matrix eigenvalues (Peterson, Smith, and Mittra, "Eigenvalues of the moment-method matrix and their effect on the convergence of the conjugate gradient method," IEEE Trans. Antennas Propagat., 1988 (in press)). Knowledge of the eigenvalue spectrum can be used to select a convergent algorithm, optimize the convergence rate of the method in use, or evaluate preconditioners for accelerating convergence rates.

A variety of examples based upon eigenvalue spectrums of both integral and differential operators will be used to illustrate applications of eigenvalue projection theory to computational electromagnetics.

Parallel Numeric Algorithms for Large Systems of Linear Equations

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ABSTRACT

In many electrical engineering applications, such as signal processing, Electro-magnetic field equations, boundary value problems, and circuit and control systems etc, the most extensive part of the computation requires solving a large system of liear equations (or linearized equations in case if the system is nonlinear). In many cases the system matrix is either sparse or ill-conditioned, requiring special attention to obtain numeric stability. With the current availability of massive multiprocessor systems using SIMD and MIMD architectures, it is now quite feasible to devise parallel algorithms for solving such systems with greater accuracy and at a much faster speed. In this paper we provide parallel versions of two commonly known algorithms namely: Conjugate Gradient (CG) method and LU decomposition. We analyse these algorithms and find the comlexities of preconditioning in CG and of finding pivots in ill conditioned systems for LU decomposition, when the system's matrix is not positive semi-definite. Finally, we compare the performance of these algorithms on various multiprocessor systems such as Hypercube, Multimax and Cray X-MP.

Parallelizing Method of Moments and its Performance on Multiprocessor Systems

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ABSTRACT

The method of moments is a basic technique for reducing functional equations, generally encountered in solving field equations, to matrix equations of a linear system. The desired accuracy of this method mainly depends on the size of the matrix used to express this system, and in many moderate size applications the size of the matrix may itself pose a serious memory storage problem. In this paper, we present a method for solving such a set of large linear algebraic equations using matrix partitioning approach. The computation uses a prallel version of LU decomposition algorithm. The complete process of solving such a system proceeds in three phases; namely pivoting, LU factorization and backward substituion to get the final solution. Each indvidual phase is implemented in form of a prallel algorithm. The performance of such a cascaded parallel structure is analyzed for the Hypercube multiprocessor system.

PRINCIPLES OF THE K-SPACE METHOD

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The scattered fields from arbitrarily shaped inhomogeneous and anisotropic structures may be computed using the k-space method. This method employs the Fast Fourier Transform with uniform zoning to achieve solutions to the general scattering problem in order $N \log_2 N$ operations where N is the number of unknowns. The k-space method was published in a 1970 report under USAF contract F33615-70-C-1345 and is the first application of FFTs to the general electromagnetic scattering problem known to the authors. While this report is occasionally referenced in discussions of continuous and discrete Fourier Transform applications in scattering theory, a number of features of the k-space method apparently remain unrecognized or at least not applied. This paper reviews the k-space approach and its application.

Topics presented are:

1. The reformulation of Maxwell's equations to an invariant representation of the fundamental $\underline{E}$ and $\underline{H}$ fields. This, in combination with a generalized constitutive equation, permits formulation of the general scattering problem using the free space Green's function. The constitutive equation relates the fields and currents to the electromagnetic properties of the scatterer which may be anisotropic and inhomogeneous;
2. The principle of domain doubling and the reduction of the impedance matrix to generatrix form for application of the FFT is discussed;
3. The discretized surface integral equation for infinite conductors is recast to volumetric form. This permits solutions of more general scattering problems for structures possessing both metallic and penetrable components without modification to the scalar Green's function. Reformulation of the surface integral equation for penetrable homogeneous scatterers, i.e., the classical Method of Moments problem, is also discussed;
4. The bistatic return in all principal scattering directions on the Ewald sphere may be computed in order N operations. How this is done using the FFT is described.

To illustrate applications of k-space, the following problems are presented: 1. The penetrable inhomogeneous slab using the 1-d Green's function, 2. the infinite strip with arbitrary resistivity distribution, and 3. the inhomogeneous penetrable cylinder of finite length using the 3-d Green's function.

Thursday AM

URSI-B Session 74

SCATTERING & DIFFRACTION - NUMERICAL METHODS

Chairmen: L. Felsen, Polytechnic University; T. K. Wu, Hughes Aircraft

Room: Newhouse 262 *Time*: 8:25-12:00

8:30	**Two-dimensional Scattering Prediction From An Arbitrary Combination Of Dielectric, Magnetic & Perfectly Conducting bodies;Survey of Theoretical & Numerical Techniques** R. C. Baucke, Rockwell International,; S. Singh, The University of Tulsa	366
8:50	**Numerical Computation of Induced Currents Inside Heterogeneous Biological Bodies by ELF-LF Electric Fields** H. R. Chuang, K. M. Chen, J. Skutnick, Michigan State Univ.	367
9:10	**On The Optimum Choice For The Coupling Coefficient(alpha) In The Combined Field Integral Equation** B. C. Ahn, A. W. Glisson, University of Mississippi	368
9:30	**A Procedure of Solving the Electric Field Integral Equation for a Dielectric Scatterer with a Large Permittivity** C. Su, National Tsinghua University	369
9:50	**Numerical Solution of Electromagnetic Problems Involving Heterogeneous Bodies Irradiated by Time-Harmonic Conducting Sources** K. D. Paulsen, The University of Arizona; D. R. Lynch, Dartmouth College	370
10:10	**COFFEE BREAK**	
10:40	**Numerical Solution of Electromagnetic Scattering by Conducting Objects over a Lossy Ground** A. Helaly, A. Sebak, L. Shafai, University of Manitoba	371
11:00	**A Method of Moments Solution for Electromagnetic Scattering from a Large Rectangular Conducting Plate with Dielectric Coatings** C. M. Morris, McDonnell Aircraft Company; J. M. Putnam, McDonnell Douglas Research Laboratories; S. D. Alspach, McDonnell Aircraft Company	372
11:20	**Radiation From Electrically Large Coated Bodies** D. Wang, P. L. Huddleston, McDonnell Douglas Research Lab.	373
11:40	**The Electromagnetic Scattering from the Circular Strip** J. T. Williams, University of Houston; D. G. Dudley, University of Arizona	374

Two-dimensional Scattering Prediction From An Arbitrary Combination Of Dielectric, Magnetic and Perfectly Conducting bodies; Survey Of Theoretical and Numerical Techniques

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A baseline combined field integral equation code has been developed. This code predicts the scattering levels from an arbitrary geometry consisting of dielectrics, magnetics, and perfectly conducting (PEC) strips. This code is used to determine the basic computational limits in speed and in size for volumetric integral equation problems. An electrically thin dielectric approximation has been added to the code which as expected reduced the number of unknowns for this common geometry. An electrically thin dielectric and magnetic strip approximation does not appear to be simple or accurate enough to be advantageous and was not incorporated into the code.

Comparisons in computation speed and accuracy are made between different PEC strip formulations, along with a comparison of the accuracy of the electrically thin dielectric strip to that of the dielectric circular cylinder. The improvement of computation speed and accuracy for large matrices has been a priority, and therefore careful consideration is given to the actual structure of the code. The code is written in a manner that utilizes the capabilities of supercomputers and vector processing. The application of iterative techniques to the matrix equation for large systems is also investigated, along with methods of approximating the impedance matrix by an acceptable sparse matrix.

Commission B

NUMERICAL COMPUTATION OF INDUCED CURRENTS INSIDE HETEROGENEOUS BIOLOGICAL BODIES BY ELF-LF ELECTRIC FIELDS

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Recently a numerical technique, the *surface charge integral equation* (SCIE) method, has been developed by our group to quantify the interaction of ELF-LF electric fields with homogeneous biological bodies and conducting objects. By using this SCIE method, the induced electric fields at the body surface and inside the body, the induced current density inside the body, the short-circuit current, and the effects of grounding impedances on the induced current in a homogeneous body of realistic shape can be computed efficiently and accurately.

A more challenging and difficult problem on this subject is a heterogeneous body case. In this paper, we report a new numerical method which combines the *impedance network method* with the SCIE method to treat a heterogeneous body. In this method, a heterogeneous body is modeled as an equivalent impedance network and the induced surface charge calculated by the SCIE method is viewed as an equivalent current source. With equivalent current sources connected at the outer boundary of the impedance network, the current flowing at any impedance can be determined on the basis of the Kirchhoff's current law (KCL). From this current, the induced current density and electric field inside the body can be mapped.

The method has been applied to a biological concentric-sphere and the numerical results agree well with an existing analytical solution. Numerical results of the induced current inside a simplified heterogeneous model of the human head (consisting of brain, bone, and muscle) computed by this method are also presented. The method can be applied to any heterogeneous biological body as long as a proper impedance network is constructed to model the body.

ON THE OPTIMUM CHOICE FOR THE COUPLING COEFFICIENT α IN THE COMBINED FIELD INTEGRAL EQUATION

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In the numerical solution of electromagnetic radiation and scattering problems involving closed, perfectly conducting bodies it is known that the Electric Field Integral Equation (EFIE) and the Magnetic Field Integral Equation (MFIE) formulations will fail at a set of discrete frequencies. The frequencies at which these formulations fail correspond to the resonant frequencies of a conducting cavity having the same boundary as the scatterer. One approach to the elimination of these non-physical resonances is the use of the Combined Field Integral Equation (CFIE). The CFIE is usually formed as a weighted sum of the MFIE and a weighting coefficient α times the EFIE. It can be shown that the solution to the CFIE will be unique for all frequencies when the weighting coefficient α is real and positive.

We investigate in this paper various choices for the coupling coefficient α in the CFIE, including complex values. It is demonstrated numerically for particular geometries that a complex value of α represents an optimum choice in some sense. The effect of changing the geometry when using this optimum choice for α is considered. The question of uniqueness of the solution to the CFIE when a complex value is used for α is also considered from an empirical point of view.

Suggested for URSI Commission B

A PROCEDURE OF SOLVING THE ELECTRIC FIELD INTEGRAL EQUATION FOR A DIELECTRIC SCATTERER WITH A LARGE PERMITTIVITY

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To calculate the scattering from or the field distributions within a dielectric scatterer, the electric field integral equation (EFIE) is widely employed. To solve the integral equation numerically, the method employing the block model in conjuction with the pulse-function expansion and the point-matching technique is quite simple in the programming and has been used for a long time. Recently, the efficiency of this method is greatly improved by a use of the conjugate gradient method (CGM) and the fast Fourier transform (FFT). However, the conventional procedure of solving the EFIE using the block model has one major drawback; that is, the permittivity of the scatterer must be kept small. Otherwise, the iteration process in the CGM converges slowly and may stagnate. Such a situation has been ascribed to an increase in the condition number of the resulting matrix as the permittivity being increased.

In this presentation, we propose a procedure of solving the EFIE using the block model, which keeps the condition number small regardless of the magnitude of the permittivity. The main features of this procedure are the two steps:

1) The node points at which the fields are to be calculated are not placed at the center of each block; rather are placed at the centers of the faces of each block.
2) Then, the polarization charge induced at an interface separating two blocks of dissimilar media (with ϵ_1 and ϵ_2) is calculated by the formula (within a multiplicative constant):

$$E_2(\epsilon_1-\epsilon_2)/\epsilon_1 \quad \text{or} \quad E_1(\epsilon_1-\epsilon_2)/\epsilon_2,$$

depending on which between the ϵ_1 and ϵ_2 is larger, where E_1 and E_2, denoting the corresponding normal components of the electric fields at the face-centered node, are related by the boundary condition $\epsilon_1 E_1 = \epsilon_2 E_2$. Note that at an interface separating two blocks of similar media, the polarization charge is set to zero automatically, as it should be.

It is the key point to note that with the ϵ_1 or ϵ_2 (the larger one) emerging in the denominator, the condition number is kept small in all situations. Consequently, the scatterer does not need to be modeled very accurately. The merits of such a procedure are that the programming task is simple and, more importantly, that the associated calculation preserves the convolution form of the EFIE and hence the FFT can be applied.

NUMERICAL SOLUTION OF ELECTROMAGNETIC PROBLEMS INVOLVING HETEROGENEOUS BODIES IRRADIATED BY TIME-HARMONIC CONDUCTING SOURCES

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Thayer School of Engineering,
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A numerical formulation is being developed for solving the Maxwell equations inside and outside arbitrarily-shaped heterogeneous lossy dielectric bodies placed in the near-field of time-harmonic sources. The technique couples finite and boundary elements as an approach to modeling the irregularly-shaped inhomogeneous object while also formally enforcing the outer boundary condition which is needed to describe the unbounded nature of the fields. In this work, sources have been treated as conducting surfaces having either finite or infinite conductivities. A known current is assumed to be injected onto each conducting surface and the resultant current and charge densities are required to distribute themselves in accordance with charge conservation. This method has been used to analyze the heating of tissue by energized electrodes for the purpose of inducing hyperthermia as a cancer therapy. Body cross-sections obtained from CT-scans of cancer patients have been digitized into finite element grids and placed between various arrangements of electrodes. Results from this study will be shown which illustrate the capabilities and limitations of heating via externally placed electrodes. These results will also illustrate the flexibility of the numerical technique for solving a general class of electromagnetic problems. While the formulation is fully three-dimensional, only results from its two-dimensional counterpart will be shown in this presentation.

NUMERICAL SOLUTION OF ELECTROMAGNETIC SCATTERING BY CONDUCTING OBJECTS OVER A LOSSY GROUND

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An approximate numerical method is developed to determine the electromagnetic wave scattering by conducting objects located above a lossy half-space. The incident field of the exciting sources, i.e. dipoles or loops which are located above or within the lossy ground, is determined using the dyadic Green's functions for a half-space (C. T. Tai, Dyadic Green's Functions in Electromagnetic Theory, Intext, San Fransisco, 1971). The scattering problem is then formulated using the magnetic field integral equation of an unbounded region, but keeping the incident field of the half-space. The method of moment is then used to reduce the integral equation to a matrix one to determine the induced surface currents on the object.

The surface currents of the object represent a set of electric dipoles distributed tangentially on the object. The dyadic Green's functions of the half-space are again used to compute the scattered field of the object, which is due to the electric dipoles with their appropriate amplitude distributions, i.e. dipole moments, and orientations determined by the object shape. An arbitrarily oriented dipole is represented in terms of its vertical and parallel components with respect to the air-earth interface.

The method reduces the complex scattering problem of objects over a lossy ground to a simpler one for determining the field of elementary sources over a lossy half-space and the solution of the standard magnetic field integral equation. The results of the method and their accuracy as well as the effect of the ground conductivity and frequency etc., will be presented and discussed.

A METHOD OF MOMENTS SOLUTION FOR ELECTROMAGNETIC SCATTERING FROM A LARGE RECTANGULAR CONDUCTING PLATE WITH DIELECTRIC COATINGS

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The scattering from a rectangular , perfectly electrically conducting (PEC) plate with thin dielectric coatings is analyzed by the method of moments . The E-field and H-field equations are applied to the dielectric regions and the E-field equation is applied to the PEC . Entire domain expansion functions and Galerkin testing functions are so chosen that the resulting system of equations is efficiently generated , has the property of decoupling into four smaller independent systems of equations , and requires only the currents bounding free space as the unknowns . A computer code making use of these properties has been written and sample computations are compared with experimental data .

RADIATION FROM ELECTRICALLY LARGE COATED BODIES

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This paper discusses the accuracy of the method of moments (MM) solutions using various integral-equation formulations when they are applied to electrically large, perfectly conducting bodies coated with materials satisfying the impedance boundary condition(IBC). It has been shown that the electric- and magnetic-field integral equations (EFIE AND MFIE) can lead to erroneous scattering results at frequencies near the internal resonances of the scatterer (J. R. Rogers, IEEE Trans. Antennas Propagat. AP-33, 462, 1985). There is also evidence indicating that the use of the MM techniques in solving the EFIE and MFIE produces spurious scattering results at frequencies away from the internal resonances (J. R. Mautz and R. F. Harrington, A.E.U. vol. 32, 157, 1978). For electrically large scatterers, further deterioration in the scattering results is noted in the present investigation. To circumvent these problems, one can employ the combined field or the combined source integral equation formulation (CFIE or CSIE). We will examine how the accuracy of the surface currents is affected by the use of various integral equation formulations. We will also discuss the advantages and disadvantages of the various formulations in treating radiation problems.

The Electromagnetic Scattering from the Circular Strip

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The axially excited circular strip is an ideal canonical scattering structure for use in system and target identification studies and in transient antenna range experiments. It offers a tractable theoretical solution, and it is relatively easy to model experimentally. In addition, the axially excited circular strip is a useful model for determining the effects of surrounding vertical antennas with passive, metallic walls or fences. It will be shown that such fences can have a significant effect upon the radiation pattern of the antenna.

An electric field integral equation is formulated in terms of the current induced on the surface of the strip and solved using the method of moments (MOM). Using the MOM formulation, we determine the fields scattered from the circular strip, in both the frequency and time domains. The frequency domain analysis is applied to the to the problem of fencing small vertical broadcast antennas. We find that appropriately designed fencing can enhance the ground wave of the antenna, while decreasing the sky wave. In addition, we determine that the radiation efficiency of the antenna is sensitive to the size of the circular strip, and that the radiation efficiency displays resonant behavior when the frequency of operation is near a natural resonace of the circular strip. We, also, calcuate the time domain transient scattered fields for different circular strip geometries, using the MOM formulation and the geometrical theory of diffraction (GTD). By deemphasizing the low frequencies in the transient pulse spectrum, we obtain good agreement between the GTD early time scattering and the transient scattering determined from the MOM formulation.

Thursday PM

URSI-B Session 75

WAVEGUIDE ARRAYS

Chairmen: D. Chang, University of Colorado;
K. Demarest, Univ. of Kansas

Room: Sheraton Amphitheater *Time*: 1:25-5:00

EFFECTS OF CROSS-PLANE SCANNING IN AN ARRAY OF PRINTED-CIRCUIT LEAKY-WAVE LINE SOURCES

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A new type of linear phased array of parallel leaky-wave line sources for millimeter waves was described recently (P. Lampariello and A. A. Oliner, European Micr. Conf., Rome, Italy, pp. 555-560, Sept. 1987) that furnishes a two-dimensional scan over a sector of space by frequency or electronic scan in elevation and phase scan in the cross plane (and therefore in azimuth). The line sources were derived as printed-circuit versions of the offset-groove-guide leaky-wave antenna; the line-source structure may be viewed, however, as a flat dielectric-filled rectangular waveguide with an unsymmetrical continuous slit in its top wall, leaking power into an air-filled upper stub of finite height. The excitation in the lower waveguide is polarized vertically, but because the continuous slit is asymmetrical a horizontally polarized field is excited in the upper stub in the form of a TEM mode that propagates at an angle and radiates from the open upper end of the stub. The width and location of the slit control the leakage rate and therefore the width of the radiated beam. The parallel-plate stub region is made sufficiently narrow that the vertically polarized field there is below cutoff; as a result, negligible cross polarization is present in the radiated field.

An accurate transverse equivalent network has been derived for the array of such line sources that employs a unit-cell approach and therefore takes all mutual coupling effects completely into account. This network has been used to obtain the performance characteristics of the array, and in this paper we present the various interesting effects produced when the array is scanned in the cross plane.

The discontinuity present at the radiating open end introduces several key features. The first is that a standing wave in the vertical direction is produced in the air-filled stub region, so that the leakage rate, and therefore the beam width in elevation, depends on the height of the stub. The second is that another set of leaky modes, the channel-guide modes, is excited, and that under appropriate conditions these modes can couple to the desired leaky mode and produce interesting dispersion behavior. As the beam is scanned further away from the vertical position, the magnitude of these two effects increases. During the scan process, the beam executes a conical scan. However, the discontinuity at the open end is a function of the scan angle, so that a deviation from strict conical scan occurs; the deviation is found to be small, though. The last effect to be discussed is the possibility that blind spots may occur during the scan process, particularly since the discontinuity changes during scan; we demonstrate in two ways, however, that no blind spots are found.

ANALYSIS OF SLOT RADIATORS IN THE BROAD WALL OF A RECTANGULAR WAVEGUIDE TUNED BY INDUCTIVE METALLIC POSTS

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A rigorous field analysis of slot radiators in the broad wall of a rectangular waveguide tuned by metallic posts and fed by the dominant waveguide mode is presented. The slots are assumed of arbitrary number and orientation and radiate into a homogeneous half-space. The posts are assumed uniform along the narrow side of the waveguide, but are otherwise of arbitrary cross-section and thickness, i.e., of the inductive type. These radiators have the distinct advantage in that individual slots in an array can be tuned to produce specified radiation patterns. Methods for the efficient handling of the various Green's functions involved in the analysis, as well as some of the results obtained, are also presented.

LINEAR ARRAY OF COAXIALLY-FED MONOPOLE ELEMENTS WITH WAIM SHEET IN A PARALLEL PLATE WAVEGUIDE

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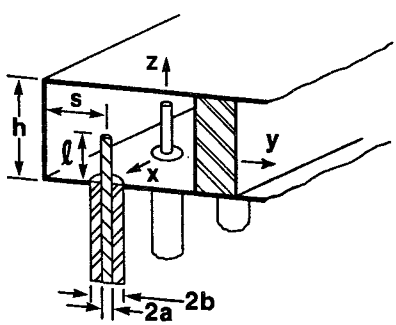
Linear arrays of coaxially-fed monopoles radiating into a parallel plate region are used extensively in various space-fed microwave array antenna systems. In particular, such arrays are employed in space-fed beam forming networks. In addition, the information derived from the study of these arrays is very useful in the design of a large variety of conformal arrays. The performance of a coaxially-fed monopole element in an infinite array environment in a parallel plate guide has been analyzed extensively in (B. Tomasic and A. Hessel, IEEE AP-T, March 1988).

In this paper we have gone one step further. Namely, we analyzed the same array with a dielectric sheet to improve its impedance match over wide scan angles and frequency, a so-called WAIM sheet (E. G. Magill and H. A. Wheeler, IEEE AP-T, January 1966). The analysis takes into account the geometry of the coaxial feed. Expressions for active admittance, coupling coefficients and element patterns are derived. Preliminary numerical results will be presented for judiciously selected parameters, which illustrate the various design trade-offs.



TAPER OPTIMIZATION FOR SIDELOBE CONTROL IN MILLIMETER-WAVE METAL-STRIP-LOADED DIELECTRIC ANTENNAS

J. A. Encinar, M. Guglielmi and A. A. Oliner
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It is generally assumed that the class of periodically loaded dielectric antennas cannot be successfully designed for low sidelobes. This viewpoint stems from empirical approaches discussed in the literature that have shown only limited success, a situation due in part to the lack of an accurate theory but also to the difficulty in being able to control separately the phase and leakage constants of the antenna. For leaky-wave antennas comprised of a metal-strip grating on a dielectric image guide, we have addressed both of these difficulties. An accurate theory has recently become available (M. Guglielmi and A. A. Oliner, Proc. European Micr. Conf., pp. 549-554, Rome, Italy, Sept. 1987), and, in this presentation, we demonstrate how we overcame the second difficulty.

As a challenging but practical example, we chose a Taylor aperture distribution corresponding to a narrow beam (about 2°) and to sidelobes 35 dB below the main beam. The procedure is first to specify the variation of the leakage constant α along the antenna length consistent with the Taylor distribution, and then to determine the changes in the antenna geometry required to realize this α variation, while maintaining the phase constant β the same. One seeks the best dimensional parameter to alter in this design, but inevitably β is changed somewhat in the process. The usual procedure is to then proceed *sequentially;* first, optimize for α, and then adjust an appropriate second parameter to compensate for the change in β. In the antenna type under consideration, only the width and location of the metal strips are accessible parameters. By following the sequential procedure together with our new theory, we achieved quite decent results, but with some degradation. We therefore developed a new procedure in which both strip widths and spacings are changed *simultaneously;* the final result yields the taper in dimensions along the antenna length that corresponds precisely to the 35 dB Taylor distribution.

The optimization procedure thus yields the width of each metal strip and the spacing between adjacent strips for the whole structure. Since the strips can be deposited lithographically, or the spacing etched away, this procedure allows one to design a mask that accomplishes the geometric arrangement all at one time. This feature is particularly attractive at millimeter wavelengths, where fabricational simplicity is an important concern.

THE MOMENT METHOD APPLIED TO AN INFINITE ARRAY OF SLOTS FED BY COPLANAR WAVEGUIDE

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Coplanar waveguide has come into use lately in monolithic microwave integrated circuits because of its low inductance ground connections for active devices and its capability for both shunt and series connections. It also can be used to reduce the physical length of a transmission line interconnection between devices. It has great potential for feeding slot antennas. The fields of a slot antenna fed by coplanar waveguide have previously been reported (D. F. Hanson, 1987 IEEE AP-S International Symposium Digest, Vol. I, 107-110, 1987) using the moment method.

Interest in developing monolithic microwave integrated circuit antennas for phased arrays is high. An integral equation for the case of an infinite array of slots fed by coplanar waveguide is derived. A series acceleration technique (R. Lampe, P. Klock, and P. Mayes, IEEE Trans. Microwave Theory Techn., Vol. MTT-33, 734-736, 1985) is developed and applied. Finally, the moment method is used to obtain a matrix equation to be solved.

CROSS-POLAR CHARACTERISTICS OF MULTI-COAXIAL CUP PRIME FOCUS FEEDS.

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The goal of the work presented in this paper is to provide a theory that will render possible the optimization of the central waveguide radius and the coaxial cup sections depth and radii ,for the small primary focus feed for shallow parabolic dishes under question.

A necessary step is to allow the method of moment solution to accommodate multimode propagation in all regions.The coupling effects between TE and TM modes of the inner waveguide and coaxial cups are investigated and incorporated into the computer solution.

The radiation properties of TE and TM coaxial cup modes are analyzed and plotted for various combinations of cup depth and radii.

Computer generated patterns establish the fact that cross-polar levels below -30dB are easy to obtain and compare favorably with published experimental data (Kumar,A.,Microwaves, March 1978 and also Collin,R.E.,H.Schilling and L.Hebert,Report No. NASA CR-167934,July 1982).

MUTUAL COUPLING IN ARRAYS OF DIFFERENT COLLINEAR RECTANGULAR WAVEGUIDES

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A number of different formulations are given in the literature for mutual coupling between identical collinear rectangular waveguides opening into an infinite ground plane (e.g. R.J. Mailloux, IEEE AP-17, pp. 740-746, 1969; T.S. Bird, Elect. Lett. 23, pp. 1199-1201, 1987). In an analysis of this problem by the Green's function approach fourfold integration over the source and field apertures is needed to calculate the mutual admittances between the modes in the apertures. Two possible methods of reducing the order of integration in the case of rectangular apertures are: a change of variables (originally due to Lewin), and replacement of the Green's function by its Fourier transform equivalent. The advantage of the first method is that the resulting double integral has finite limits.

In this paper we show that both methods are applicable to coupling between different size rectangular waveguides. Mutual admittance expressions obtained by the first method will be presented for all possible combinations of TE and TM mode coupling. The efficacy of the solution will be demonstrated for adjacent waveguides coupling in their E- and H-planes and also for excitation of the cross-polarized TE_{01} mode by the TE_{10} mode for waveguides coupling in the inter-cardinal planes.

SPECTRAL DOMAIN ANALYSIS OF LEAKY-WAVE ANTENNAS FOR MILLIMETER WAVES

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Recently leaky-wave antennas have been the focus of attention as a low-cost alternative for use with millimeter integrated circuits. One mechanism used to introduce leakage and thereby produce an antenna is the deposition of small periodic metal strips on the top surface of a dielectric image guide.

An alternative for producing leakage is to load the grounded dielectric sheet with a top (superstrate) layer. In order to analyse the basic properties of this structure the Greens function is determined as a first step. Following the well known procedure introduced in connection with the theory for microstrip antennas with a superstrate the problem is stated using integrals of Sommerfeld type. Typically, the farfield solution of the Sommerfeld integrals is obtained by the method of steepest descent. By this the complete solution is composed of the contribution of the saddle point and of the poles. The latter are surface-wave (real) poles and leaky-wave (complex) poles. Here we have to deal with the problem that a structure with a strong leaky-wave excitation is required. This occurs, if a complex pole is located close to the real axis. Therefore the migration of the complex poles as a function of the parameters of the layered structure is discussed in detail.

The farfield pattern of a point source located in a microstrip structure is so far calculated from the saddle point contribution. In the case of a strong leaky-wave exitation one would suppose that the contribution of the corresponding complex pole, which is calculated by the residue theory, must be added. Doing this, the following difficulty arises: According to the residue theorem, the contribution of a pole must only be taken into account if it is captured during the path deformation required by the method of steepest descent. Numerical solutions of the Sommerfeld integrals show, however, that a leaky-wave excitation also occurs if a complex pole is not captured by the path of steepest descent. Another problem arises because of the restricted range of validity of the asymptotic solution described so far: This is only true, if no pole singularity is close to the saddle-point. In many interesting cases this restriction is often not satisfied. Then the modified method may be used, the application of which is often somewhat complicated. An alternative is to find a numerical solution of the Sommerfeld integrals. Since the convergence of these integrals is very poor for the farfield pattern, a numerical solution is not adaquate for an optimization procedure. Therefore in a first step the radiation pattern is determined by the simple method of steepest descent in order to discover sets of parameters for a considerable leaky-wave exitation. In a second step the radiation pattern is accurately calculated applying numerical integration in order to find the parameters for strong leakage.

A considerable improvement of the radiation pattern is obtained using a linear array of rectangular patches instead of a point source. The phases of the antenna currents are adjusted for radiation in the direction of the leakage. For the determination of the required phases of the source currents an integral equation is formulated for the antenna currents in the spectral domain and it is solved by the method of moments including the effect of mutual coupling. The radiation pattern of the array is then obtained by multiplying the array pattern and the element pattern.

COMPUTATION OF SELF AND MUTUAL-ADMITTANCE BETWEEN TWO LONGITUDINAL SLOTS IN THE BROAD-WALL OF A THIN RECTANGULAR WAVE-GUIDE

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ROORKEE-247667(INDIA)

ABSTRACT

The present state-of-art in the design of waveguide-fed slotted arrays lies in reducing the height of the waveguide and lengthening of slots. As a result the effect of external mutual coupling as well as internal mutual coupling due to both propagating and non-propagating higher order modes can no longer be neglected. In 1983, a general theory was presented, that would permit the design of linear and planar arrays of wave-guide fed slots including the effects of external mutual coupling [R.S.Elliott,AP-33, No.11, 1264-1271, 1983]. The theory is mainly based on experimental data [Stegen R.J., Hughes Technical Memo 261, Hughes Aircraft Co., USA, 1951] for self-admittance of a single slot, it's length and offset. The information is then used for design equations taking into account mutual coupling as well. The procedure is costly, time-consuming and less accurate for high-performance array designing.

In this paper, a theoretical model based on moment method has been described, that would replace experimentally obtained input data by theoretical data generated with sufficient accuracy, less cost and time. The analysis allows direct computation of self and mutual-admittances based on scattering parameters calculated theoretically. It takes into account the effects of internal mutual coupling due to both propagating and non-propagating modes and external mutual-coupling as well, giving more-reliable data.

The geometry of the problem is shown in Fig.1. The functional equations are derived by applying equivalence principle in conjunction with appropriate boundary condition for the tangential components of $\vec{H}$ field applied to each slot. The equations are solved by Galerkins method. The choice of piecewise trigonometric function to model electric field in the slots gives a more realistic approach, at the same time reduces the computation storage and run-time requirements.

Computed results are presented to show the variation of self and mutual-admittances of these slots as a function of slot-lengths and their offsets from the center line. Also the variations of self and mutual conductance and susceptance as a function of offset for two resonantly spaced half-wavelength slots are shown separately.

Thursday PM

Joint AP-S, URSI-B Session 76

MICROSTRIP ANTENNAS

Chairmen: Y. T. Lo, University of Illinois; M. Calvo, Politechnic of Madrid

Room: Sheraton Regency A *Time*: 1:25-4:40

IMPEDANCE PARAMETERS AND RADIATION PATTERN OF CYLINDRICAL-RECTANGULAR AND WRAPAROUND MICROSTRIP ANTENNAS

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Cylindrical microstrip antennas find many applications pertaining to high speed aircrafts and spacecrafts, because of their conformity with the aerodynamical structure of such vehicles. Recently there has been some progress in the theoretical study of such antennas. In the papers by Fonseca et al. (S. Fonseca and A. Giarola, *IEEE Trans. Antennas Propagt.,* vol. AP-31, no. 2, March 1983) and Ashkenazy et al. (J. Ashkenazy et al., *IEEE Trans. Antennas Propagt.,* vol. AP-33, no. 3, March 1985), the radiation from various cylindrical microstrip elements was computed by assuming an electric surface current distribution on the microstrip patch. The excitation problem of realizing such a current distribution was not addressed in these papers. Furthermore, the input impedance for the cylindrical microstrip antennas was not reported.

In this paper we address the more realistic problem of the radiation from a cylindrical microstrip antenna excited by a probe. Both the cylindrical-rectangular and the wraparound elements are discussed. The current distribution on the patch is rigorously formulated using a cylindrically stratified medium approach. A set of vector integral equations are derived which governs the current distribution on the patch. This set of equations is then solved using Galerkin's method in which the patch current is expanded in terms of a complete set of basis functions that can take into account the edge singularity condition. The input impedance together with the radiation pattern are derived both exactly and in the small substrate thickness limit where a single mode approximation is employed.

An Efficient Moment Metod Analysis of Finite Phased Arrays of Microstrip. Dipoles Using An Asymptotic Closed Form Approximation for the Planar Microstrip Green's Function

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An efficient analysis of a finite phased array of microstrip dipoles which employs the newly developed closed form asymptotic representation for the planar microstrip Green's function is presented. Such an analysis is of importance to the proper design of monolithic phased arrays which are gaining popularity for applications in the millimeter wave regime.

The full wave array analysis via the Moment Method (MM) requires one to calculate the mutual coupling between all possible pair of the elements in the array (some of these are identical via symmetry considerations). The exact Plane Wave Spectral (PWS) integral representation for the microstrip surface Green's function has been utilized previously for such calculations [D. M. Pozar, IEEE Trans. Antennas and Propagations, AP-33, pp. 1045-1053 , 1985]. However, these calculations require long numerical computational times; e.g., about two hours of CPU time on a VAX 11/750 for 19 × 19 element array as indicated in the preceeding refrence. In order to drastically reduce the above computational times, the aformentioned asymptotic closed form approximation for the planar microstrip Green's function [S. Barkeshli, P. H. Pathak, URSI, Radio Science Meeting Digest, pp. 177, 1986] and [S. Barkeshli, Ph.D. Dissertation, The Ohio State University, 1987] is utilized. This closed form asymptotic approximation remains accurate even for very small (e.g., a few tenths of a wavelength) lateral separations between the source and field points.

The various quantities of interest, such as the active impedance and active reflection coefficient versus scan angle have been found using the present approach for various size arrays. The numerical efficiency of this newly developed approach will be described.

SCATTERING FROM AN IMPEDANCE LOADED PRINTED DIPOLE ARRAY

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A theoretical model for obtaining the scattering characteristics of a two-dimensional infinite array of dipoles printed on a dielectric coated conductor is considered.

The dipoles are mounted in a rectangular array and illuminated by an incident plane wave of arbitrary incidence angle. Each element is impedance loaded in the center. The approach taken is to decompose the problem into two related problems--scattering from an array of shorted dipoles and transmission from an array of dipoles. A dyadic Green's function approach is used to determine the fields due to the induced currents on the dipoles. The currents are modeled using sinusoidal basis functions with no variation across the width of the dipoles. Galerkin's method is used to solve for the dipole currents.

The power absorbed by the load impedance as a function of frequency, incidence angle and polarization, as well as of the array geometry and dielectric parameters, is obtained. Control of the scattered field through variation of the load impedance is investigated.

ANALYSIS OF SEQUENTIALLY ROTATED FEEDING FOR WIDE BANDWIDTH CIRCULARLY POLARISED MICROSTRIP ANTENNAS

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The technique of sequentially rotated feeding has been recently applied to circularly polarised microstrip patch arrays and shown to give substantial increases in bandwidth for both axial ratio and input VSWR. This improvement can be attributed to the cancellation of both element cross polarisation within the radiation field and also element mismatch within the feed network brought about by the element rotation and feeding phase shifts respectively. The method also allows use of feed networks without isolating resistors which is a considerable saving in construction complexity.

In this paper we present results of an analysis of the sequentially rotated microstrip antenna and its associated feed structure that indicate both the optimum feeding arrangements and the likely performance limitations of the technique. The microstrip elements are modelled using the patch cavity model including higher order modes estimated by mode matching at the input point. Radiation patterns are calculated using a magnetic source model at the patch edge. The feed is analysed using a transmission line equivalent circuit and is representative of both coaxial or triplate line feeds or to a first approximation coplanar microstrip networks. It is shown that multiple scattering between the elements and the power splitter in the feed network, higher order mode generation in the microstrip patch elements, the use of frequency sensitive phase shift elements in the feed and mutual coupling between elements are all important aspects governing the overall performance. Closed expressions are given that highlight the relationship of these aspects to number of elements and phase progression and more detailed analysis allows the relative significance to be established.

Results will be presented both for patch arrays and for multiple point feeding of single patches. It is concluded that even in the case of very thick patches where higher order modes would be expected to be significant, the multiple reflection between the patch mismatch off resonance and the power splitter is the dominant effect in limiting the bandwidth. In the case of single patch feeding the analysis indicates that alternate feeding arrangements to those previously used will give further improvements in performance. It is also demonstrated that while increased bandwidth for axial ratio and VSWR occur, the antenna gain bandwidth is unaffected by the rotation technique.

ON THE DESIGN OF WIDE-BAND MULTIPLE-COUPLED LINES MICROSTRIP ANTENNAS

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One of the techniques suggested for increasing the bandwidth of rectangular microstrip patch antennas is the use of multiple elements coupled to each other in a composite patch configuration (Kumar and Gupta, IEEE APS International Symposium, Houston, 1983). Out of the various arrangements proposed, the patch with various elements coupled along the non-radiating edges can be designed to occupy a relatively smaller area and is therefore the most promising. A coupled-line model for analysis and design of such antennas has been proposed recently (Gupta and Bandhauer, URSI Meeting, Boulder, January 1988).

An insight into the operation of these antennas is obtained by considering the normal modes of wave propagation along the multiple coupled microstrip lines on a dielectric substrate. If we consider two identical patches gap-coupled along the non-radiating edges, the two normal modes of excitation are even and odd modes of coupled microstrip lines. Owing to the different phase velocities of even and odd modes, twin coupled resonator patch will resonate at two different frequencies (for the lowest TE_{10} modes). However, the odd-mode voltages at the two sections of each of the radiating edges are 180° out of phase, and hence their radiation fields cancel each other. Thus, for such a symmetrical design, only the even mode would radiate efficiently. On the other hand, if two coupled patches have different widths, we can obtain a substantial radiation at the resonance of the odd mode (or π mode) also.

A triple-resonator, coupled-line microstrip antenna is a better choice for broadband operation because of its three normal modes. The structure may be designed so that these three resonance frequencies are located suitably over the operating bandwidth of the antenna. In the c mode, voltages on the three sections of each of the radiating edges have the same polarity, and the radiated power is at maximum. For the other two modes, one of the three sections of the radiating edge will have a voltage polarity opposite to those on the other two, and therefore the radiated power will be smaller. By suitable adjustment of antenna parameters, it should be possible to extend the antenna gain bandwidth over the resonances of three modes.

Detailed design results for two-line and three-line antennas will be discussed.

NUMERICAL ANALYSIS OF A BICONICAL TRANSMITTING ANTENNA

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Several decades ago, the biconical transmitting antenna was analyzed [S. A. Schelkunoff, Advanced Antenna Theory, Wiley, New York, 1952], as, more recently, was the biconical receiving antenna [D. M. Grimes, J. Math. Phys., 23, 897-914, 1982]. Although these exact results have the capability of teaching us more about antennas, the complexity of the field equations has prohibited widespread useage or even understanding. Existing numerical solutions primarily provide only input impedances. Biconical antennas are the only ones that are somewhat practical and for which complete solutions are possible, for antennas of arbitrary size. For these reasons we have recently completed a numerical analysis of the biconical transmitting antenna, and are working on the receiving one. We are capable of computing transmitter solutions for all cone angles and arm lengths.

Using a system of linear equations with parameter dependent coefficients, we have obtained and programmed the relationships between the field coefficients inside and outside the antenna aperture. This required the solution of a truncated, infinite set of linear equations with parameter dependent coefficients. We developed a robust computation algorithm for the roots of odd parity Legendre functions, both inside and outside the aperture. Exact functional expressions were used wherever possible to evaluate surface integrals, with elsewhere a resort to numerical integration.

Although the far field terms converge rapidly with multipolar degree, the near fields do not. For example, our best approach to the fields in the vicinity of the cap discontinuity [D. M. Grimes, Electromagnetics, 7, 129-135, 1987] required going to degree of about thirty. Our impedance results agree with others [J. R. Wait, Antenna Theory, Collin and Zucker, eds., McGraw Hill, 1969, Chp. 12]. Field solutions will be compared cross the aperture, surface current and charges on arms and caps sketched, and the real power flow, the reactive power flow, and reactive energy density sketched as a function of radius.

HANKEL DOMAIN ANALYSIS OF ANNULAR-RING MICROSTRIP ANTENNAS WITH PARASITIC ELEMENTS

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One method for widening the bandwidth of microstrip patch antennas is to add parasitic patches having the same shape on the top of the original patches. Analysis on this type of two-layer electromagnetically coupled patch antennas has been carried out recently (K. Araki, H. Ueda and T. Masayuki, T-AP, 34, 1390-1394). The analysis based on Hankel domain transform was concentrated on the characteristics of circular disk antennas. As it is well-known that the TM_{12} mode of an annular-ring microstrip antenna has a wider bandwidth performance compared with the fundamental modes of itself and other patches, it is interesting to investigate the possibility of further increasing the bandwidth of the TM_{12} mode by the addition of parasitic elements. In this paper, we present results on the complex-resonant frequencies, far field patterns and input impedances of annular-ring microstrip antennas loaded with parasitic annular-ring patches, deriving from the Hankel domain analysis. Comparison between theory and experiment will also be demonstrated.

Thursday PM

Joint AP-S, URSI-B Session 77

SATELLITE/BROADCAST ANTENNA SYSTEMS

Chairmen: C. Christensen, Anaren Microwave, Inc.;
B. Edwards, General Electric Co.

Room: Sheraton Regency B *Time*: 1:25-5:00

1:30	**Optimization Studies of Multiple Beam Antennas for EHF Satellite Communications** W. Rotman, Massachusetts Institute of Technology	See AP-S Dig.
1:50	**Thermal Distortion Analysis on ACTS Multibeam Antenna** D. Y. Kim, C. H. Chen, K. Oye, W. C. Wong, S. J. Hamada, TRW	See AP-S Dig.
2:10	**Quadrature Mixer Analysis** A. J. Noga, Rome Air Development Center	394
2:30	**Mechanically Steered Tracking Antenna for Land Mobile Satellite Communications** A. Kuramoto, T. Yamane, N. Endo, NEC Corporation	See AP-S Dig.
2:50	**COFFEE BREAK**	
3:20	**Study Of Ferroelectric Radiating Element For Antenna In Mobile Communication Systems** C. Das Gupta, Indian Institute of Technology Kanpur	See AP-S Dig.
3:40	**A Flush-Mounted Antenna For Mobile Communications** K. Kaneta, T. Kondo, M. Ando, N. Goto, Tokyo Institute of Technology	See AP-S Dig.
4:00	**HF Broadcast Transmitting Antennas** A. Paul, Howard University	See AP-S Dig.
4:20	**The Directional Gain and Efficiency of a Travelling Wave V-Antenna In the UHF Band** E. J. May, University of Exeter; I. R. Bin-Ghunaim, Ministry of Post, Saudi Arabia	See AP-S Dig.
4:40	**Study of Installing TV Transmitting Antennas of Different Frequency Channels on the Same Horizontal Plane of a Transmitting Tower** N. Sun, J. Wang, Shanghai Univ. of Technology	See AP-S Dig.

QUADRATURE MIXER ANALYSIS

Andrew J. Noga, Rome Air Development Center

Many modern communication systems require baseband representation of bandpass signals. A noise-free bandpass signal is represented in the form x(t) = Ai(t)cos(wt) - Aq(t)sin(wt) where A is a constant, w is the carrier frequency in rad/sec, and i(t) and q(t) are some form of either one or two signals, depending upon the desired modulation. The in-phase component i(t) and the quadrature component q(t) can be recovered from the signal x(t) in one of two ways. Either the signal can be digitized at a low Intermediate Frequency (IF) and digital processing can be employed to separate i(t) and q(t), or the signal can be converted directly to baseband (DCIF) as shown in figure A. In this case separate digitizers can be used to convert the i and q signals to their sampled versions. The advantage to using this second technique is that the sample rate of the A/D converters is reduced to at least 1/2 that of the low IF technique. This implies that for a given dynamic range in an A/D converter, the DCIF technique can process signals of wider bandwidth.

Disregarding noise, wave reflections, mixer spurious, and other nonlinear distortions, the quadrature mixer's performance depends heavily upon phase and amplitude mismatches between the in-phase and quadrature channels. As an example, a mismatch of 1 degree in phase and 0.1 db in amplitude will produce an undesired image signal which is 42 db below the desired signal. The paper to be presented would be an overview of the analysis of these distortions from selected open-literature sources and from work sponsored by RADC.

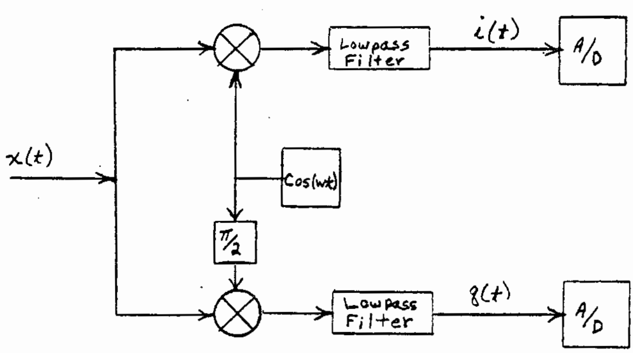

Figure A.

Thursday PM

Joint AP-S, URSI-B Session 79

SIGNAL PROCESSING ANTENNAS

Chairmen: D. Weiner, Syracuse University;
B. Steinberg, Univ. of Pennsylvania

Room: Sheraton Comstock A *Time*: 1:25-5:00

1:30	**Novel Techniques of Designing Multchannel Antenna Systems in Correlated Interferences** A. K. Gupta, GTE Government Systems Corporation	See AP-S Dig.
1:50	**A Study of the Effects of Mutual Coupling on the Direction-Finding Performance of a Linear Array Using the Method of Mements** D. H. Shau, A. T. Adams, T. K. Sarkar, Syracuse University	See AP-S Dig.
2:10	**A C-band Digital Beamforming Array** L. J. Simonangeli, A. Agrawal, RCA-ESD	See AP-S Dig.
2:30	**Adaptive Digital Doppler Filters** H. Chen, Nanjing Research Institute of Electronics Tech.; J. Li, Nanjing Research of Institute of Electronics Tech.; T. K. Sarkar, Syracuse University	396
2:50	**COFFEE BREAK**	
3:20	**An Adaptive Coded Wideband HF System for Varying Channel Conditions** A. Gupta, GTE	397
3:40	**Music Algorithm in a Scattering Environment** F. Haber, C. Zhou, University of Pennsylvania	See AP-S Dig.
4:00	**Reduction of Interfering Signals in Swept-Frequency Scattering Measurements Using Complex Wiener Filtering** D. E. Weissman, Hofstra University; L. D. Staton, NASA Langely Research Center	398
4:20	**Efficient Method Of Computing Current Distributions For Sum And Difference Channels In Direction Finder** T. B. Vu, The University of New South Wales	See AP-S Dig.
4:40	**A New Adaptive Algorithm of Frequency-Wavenumber Estimation** L. Yin, L. Zou, Xi'an Jiaotong University	See AP-S Dig.

ADAPTIVE DIGITAL DOPPLER FILTERS

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Instead of using the FFT or FIR digital filter bank, we tried to use adaptive digital filters as the Doppler filters for MTI or MTD radars. The weight vector W of the adaptive digital filter is the eigenvector corresponding to the minimum eigenvalue of a generalized eigensystem $R_{xx}W = \lambda Z_{xx}W$. R_{xx} is the covariance matrix of the input data. Z_{xx} is the covariance matrix of the noise or/and clutter contained in the input data. λ is the eigenvalue of the generalized eigensystem.

The weight vector W is iteratively calculated by the GMEVCG algorithm (Huanqun Chen, Tapan K. Sarkar et al., IEEE Trans. Acoust., Speech, Signal Processing, vol. ASSP-34, 272-284, 1986). The amount of computation of one iteration for an adaptive digital filter with 5 weights is about 35% more than that of a 32-point FFT.

The results of our computer simulation indicate that the signal spectra of two equiamplitude sinusoids at -60 dB SCR (Signal to Clutter Ratio) could be detected by a 5-weight adaptive digital filter (Fig. 1). We use a 5-weight adaptive digital filter to detect the spectrum of one sinusoid that the SCR may be down to -75 dB (Fig. 2).

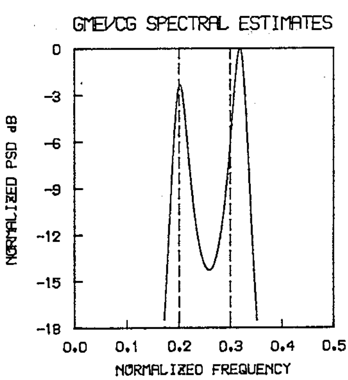

Fig. 1 5-weight GMEVCG spectral estimates of 2 sinusoids embeded in heavy clutter (SCR = -60 dB).

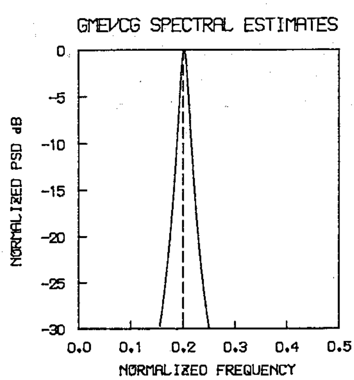

Fig. 2 5-weight GMEVCG spectral estimates of 1 sinusoid embeded in heavy clutter (SCR = -75 dB).

AN ADAPTIVE CODED WIDEBAND HF SYSTEM FOR VARYING CHANNEL CONDITIONS

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This paper discusses an adaptive high data rate (up to 24 kbits/sec. with an error rate of tenth power of -4) jam resistant HF communication system for high quality information transmission, including digital voice, through time-varying channel conditions in single-hop ionospheric path established in mid-latitude or in trans-auroral belt. The proposed method employs coded (e.g. block, convolution and concatenated) diversity system in addition to previously proposed MFSK signalling with waveform diversity (A.K. Gupta and M.D. Grossi, Proc. of Ionospheric Effects Symposium, Alexandria, VA, 282-296. 1981).

The concatenated codes may be the combination of any two codes or a code and a spatial diversity system. For MFSK signalling, further processing gain is shown to be possible by this author proposed whitening techniques (A.K. Gupta et al., IEEE Trans on ASSP, June 1986).

REDUCTION OF INTERFERING SIGNALS IN SWEPT-FREQUENCY SCATTERING MEASUREMENTS USING COMPLEX WIENER FILTERING

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A new approach to the reduction of scattered, interfering signals that corrupt measurments of the signal backscattered from radar targets of interest is being developed. This method is based on the concept of Wiener filtering (which minimizes the difference between the signal plus noise and the desired signal in the time domain). In contrast to the traditional Wiener filter, in which the time domain difference between two sequences are minimized, the approach reported here employs the frequency domain phasor amplitudes of a swept frequency signal. It minimizes the difference (least-mean-square-magnitude) between the signal-plus-noise and the signal complex phasors, across the entire spectrum. The Wiener filter therefore has complex coefficients which act on the phasors associated with the sequence of frequencies. The design of the filter is based on the complex autocorrelations of the signal-plus-noise and the noise. This approach is attractive in radar range measurments where the support structures create interfering backscattered waves.

The performance of the filter can be chosen by selecting the number of coefficients. Their number can be increased as desired (up to some small fraction of the total number of data points). For example, in the case of a 2-inch sphere immersed in random noise that is about 5.5 db stronger (averaged over the 1024 frequencies), a 48 complex coefficient Wiener filter will reduce the time domain noise by a minimum of 10 db at almost all the time domain points. Increasing the number of coefficients will result in even greater reduction. Also, if other localized sources of spurious reflection are to be suppressed, their autocorrelation function at the receiver (in the frequency domain) can be used to optimize the filter.

Thursday PM

URSI-F Session 80

RADIO AND RADAR METROLOGY

Chairmen: E. Smith, University of Colorado; M. S. Pontes, CETUC

Room: Sheraton Comstock B *Time*: 1:25-5:00

OPTIMAL RECEPTION IN DEPOLARIZING RAIN CLUTTER

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This research is directed towards developing methods of power optimization that might prove fruitful for analyzing rain signatures and for suppressing/enhancing rain clutter/target. Using coherent measurements of the backscattering matrix, the time-averaged Mueller matrix is constructed so as to characterize a time-varying rain-cell from a partial polarization viewpoint. This Mueller matrix is used to calculate the ellipticity and tilt of the transmitted field which optimizes the adjustable power in the received field (JOSA A Ser.2,Vol.5(1), pp. 58-64, Jan. 88); only transmitted fields which are completely polarized are considered. Values of ellipticity and tilt can then be correlated against available ground-truth data to aid in the analysis of rain signatures, calibration of the radar system, or simply as a method for treating rain as clutter or target.

The optimization procedure has been recently tested against suitable X-band backscattering matrix measurements. Preliminary results indicate that linearly polarized fields (ellipticity of zero and tilt of 80 degrees) are "best" to transmit. The 80 degree tilt angle (from horizontal) seems to compare with the small canting angles (from vertical) observed by meteorologists. The optimal adjustable power seems to correlate with the average rain rate, but it is also a function of the wind speed gradient and direction.

DUAL POLARIZATION RADAR OBSERVATIONS OF A COLORADO HAILSTORM

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Dual linear polarization radars (at S-band frequencies) have been shown to be able to discriminate hail regions from the surrounding rainfall regions in severe storms (Aydin et al., J. Climate Appl. Meteor., 25, 1475-1484, 1986). This hail detection technique is based on the differences (clustering) in the backscattering properties of raindrops and hailstones at horizontal (H) and vertical (V) polarizations. Raindrops, due to their oblate spheroidal shape and alignment of minor axes along the vertical direction, create an anisotropic medium producing a larger radar return at H-polarization relative to V-polarization (the difference between the reflectivity factors at H and V polarizations in decibels is defined as differential reflectivity or Zdr ;Seliga and Bringi, J. Appl. Meteor., 15, 69-76, 1976). On the other hand, hailstones are generally more irregular in shape and tend to wobble and tumble as they fall, thus creating more of an isotropic medium producing very similar radar returns at H and V polarizations, which are generally higher than the returns due to rain.

This paper utilizes the Zdr hail detection technique to discriminate hail regions in the June 13, 1984 hailstorm that occurred near Denver, Colorado, using the National Center for Atmospheric Research's CP-2 radar system. Within the identified hail regions the reflectivity factors at H-polarization (Zh) are categorized in 5 dB increments ranging from 35 to 70 dBZ during different time intervals and at various heights in the storm. The mean differential reflectivities (Zdr) in these categories are determined and are seen to exhibit variations with height and time. The area-time integral of both Zh and Zdr also exhibit significant variations with height. Interpretations of these observations in terms of the characteristics of the hail medium are made, and studies necessary for improving these interpretations are suggested.

PREDICTING ATTENUATION AND DEPOLARIZATION ALONG 10-30 GHZ EARTH-SPACE PATHS USING DUAL-POLARIZED RADAR

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Virginia Polytechnic Institute and State University
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The most important meteorological parameters in slant path propagation through a rain medium are the size, orientation, and shape of raindrops. These three parameters can be described by: (i) a Gamma drop size distribution (DSD) with parameters N_μ and Λ_μ in a DSD equation of the form $N(D_e) = N_\mu D_e \exp(-\Lambda_\mu D_e)$, where D_e is the diameter of a spherical equivolume raindrop; (ii) a Gaussian canting angle distribution with a mean $\langle\theta\rangle$ and a standard deviation σ_θ ; and (iii) a discrete shape distribution with F_o the fraction of the drops which are oblate, the remainder being spherical. Since specific rainfall attenuation (A) is proportional to the cubic power of D_e, and radar reflectivity (Z) is proportional to the sixth power of D_e, correct knowledge of the DSD is vitally important in predicting attenuation from radar measurements. The Virginia Tech multiple polarization Octopod radar has eight linear polarizations, and is used to collect reflectivity (Z) and differential reflectivity (ZDR) data as input for a forward scattering analysis program, which calculates attenuation (A) and cross polarization discrimination (XPD) on the slant path.

The connection between backscatter and forward scatter is accomplished through curve fits for the relationships between Λ_μ and ZDR, Z_H/N_μ and Λ_μ , and between R/N_μ and Λ_μ. (Z_H/N is the normalized horizontal reflectivity of the medium, and R/N_μ is the normalized rain rate.) We use staatically determined values for parameters F_o and σ_θ , with values of $\mu = 0$, 2, and 5. The curve fit data is derived from rigorous backscatter calculations for each of these relation- ships, starting with a given DSD and setting each of the other parameters to a wide range of values. The radar measured Z and ZDR values are used to calculate the corresponding N_μ and Λ_μ values in each range bin for a given μ . The DSD parameters determined for each range bin are then used in the forward scattering analysis program , which calculates A and XPD on the path, with the corresponding values of F_o and σ_θ .

The program calculates the medium depolarization matrix $[D_T]$ from $[D_T] = [D_1] [D_2] \ldots [D_i] \ldots [D_m]$, where $[D_i]$ is the depolarization matrix for the i-th range gate, and i = m corresponds to the bottom of the melting layer. Rainrate R is determined from the DSD parameters of each range bin. The A and XPD calculations avoid the usual rain rate step, and eliminate the need for storm-dependent A-Z-R relationships, resulting in higher accuracy in A and XPD predictions.

(*) Now at RCA Astro Space Division, Princeton, New Jersey

Hydrometeor Scattering in 53- and 118-GHz Observations of Brightness Temperatures over Precipitation Cells

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Nadiral observations of microwave brightness temperature over convective precipitation cells have been made using two narrowband O_2 channels at 53.65 GHz and 118.75±1.47 GHz. The observations were made using a multichannel millimeter-wave imaging spectrometer on board the NASA ER-2 high-altitude aircraft during the Cooperative Huntsville Meteorological Experiment (COHMEX) 1986. The two channels have similar clear-air nadiral temperature weighting functions (Fig. 1), hence yield nearly identical brightness temperatures over cloud-free regions.

The response of the two channels to liquid and frozen hydrometeors, however, is markedly different. Over precipitating regions, small negative perturbations ($\leq$35 K) in the 118-GHz brightness temperature are found to be 2-3 times as large as coincident 53-GHz perturbations. Such perturbations are common over weak precipitation. Negative 118-GHz perturbations larger than 35 K track coincident 53-GHz perturbations more closely, and have been associated with strong convective precipitation. A scatter plot of the perturbed brightness temperatures for the two channels is shown for observations of precipitation on June 29, 1986 (Fig. 2).

The observed brightness temperature perturbations have been compared to numerical results from a simple one-dimensional radiative transfer model incorporating an ice-phase scattering layer. The ice layer was assumed to extend from 7 to 10 km, consistent with coincident radar observations. Ice particles were assumed to have Mie scattering cross-sections and equal forward- and back-scattered components. Brightness temperatures were computed for ice densities up to 5.0 g/cm^2 (13.8 g/m^3) for selected particle radii between 100 μm and 1.5 mm (Fig. 3). The calculated 118- and 53-GHz perturbations match the observations most closely for $\approx$1 mm particle radii, but are quite sensitive to the assumed particle size and density.

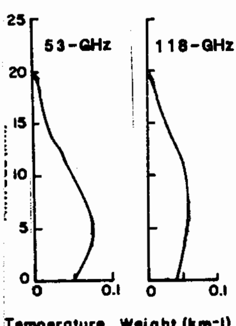

Figure 1.

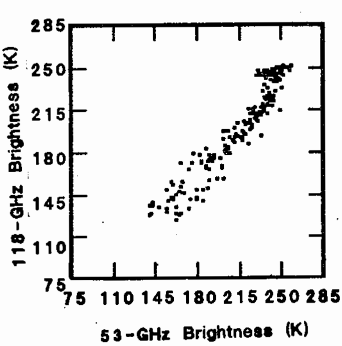

Figure 2.

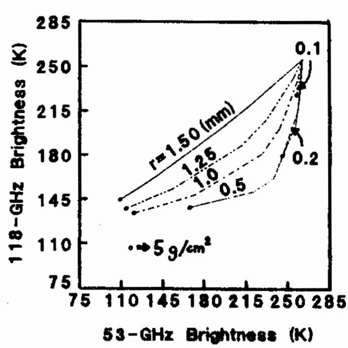

Figure 3.

RAIN-SCATTER INTERFERENCE ON MICROWAVE COMMUNICATION LINKS

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Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802

A rain-filled medium along a microwave communication link can scatter signals in various directions producing interference at other receiving stations. This rain-scatter interference can affect both terrestrial and satellite communication links. The problem is especially important in those parts of the world (e.g., Europe) where such communication links are increasing in number within fixed frequency bands. Computational studies of rain-scatter interference have been performed in the past using spherical shapes for rain drops and Laws and Parsons or Marshall-Palmer raindrop size distributions both of which represent widespread continental type rainfall. A number of these studies also utilized the Rayleigh scattering approximation at X-band and higher frequencies. In this paper we consider the rain-scatter interference problem at 11 and 30 GHz frequencies between a satellite-based communication earth station and a terrestrial line-of-sight communication terminal. We compare the interference caused by two different types of raindrop size distributions: the Joss-thunderstorm and Marshall-Palmer drop size distributions. We also compare the effects of spherical and oblate spheroidal (which is a more realistic model) models of raindrop shape. Results are presented for both vertical and horizontal polarizations. The electromagnetic scattering computations are performed using Waterman's extended boundary condition formulation (also known as the T-matrix method) which does not involve the Rayleigh scattering approximation.

MEASUREMENTS OF RAIN RATE AND RADIOMETRIC SKY TEMPERATURES AT 12 GHz IN TROPICAL AND EQUATORIAL CLIMATES

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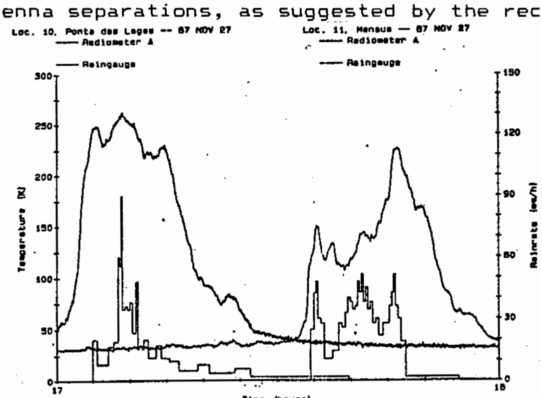
R.Mqs.S.Vicente,225 - Rio de Janeiro - 22453 - BRAZIL

In november 1987, radiometric sky temperature and rain rate measurements were initiated at four sites in Brazil, as part of a cooperative program with the Canadian Research Centre, that provided the necessary equipment. The main goal of the program is to investigate the impairment due to rain attenuation in satellite links at frequencies above 10 GHz, in tropical and equatorial climates. Each experimental set-up consists of a dual-slope radiometer system operating at 12 GHz, which samples and records sky noise temperature every two seconds, and a tipping bucket raingauge. The time of each tip is also recorded by the system.

The locations chosen, their climates and the respective elevation angles of the radiometer antennas are as follows:

	LATITUDE	LONGITUDE	CLIMATE	ELEVATION
MANAUS	03°08'S	60°01'W	equatorial	78°
PONTA DAS LAGES	03°06'S	59°54'W	equatorial	78°
BELEM	01°27'S	48°29'W	equatorial	65°
RIO DE JANEIRO	22°55'S	43°30'W	tropical	52°

Statistics of rain rate and equivalent attenuation obtained during the 1987-1988 summer in Brazil will be presented. Since the distance between Manaus and Ponta das Lages is only 9 km, the effect of employing space diversity is also evaluated. Preliminary results already available, indicate that this technique can be effective even for such short antenna separations, as suggested by the record below.



*** COMMISSION F

THE CHARACTERISTICS OF RAIN RATE DISTRIBUTIONS FOR VARIOUS INTEGRATION TIMES AND DATA PERIODS

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P. O. Box 71, Chung-Li, Taiwan, R. O. C.

ABSTRACT

Some statistics of shorter rainfall rate are applied for microwave system design at frequency above 10 GHz. In plan to establish shorter-time rainfall observing systems for collecting data, to adopt a suitable integration time for an acceptable measuring period and from economical benefit viewpoint is an important consideration. This paper makes an investigation on the varieties of cumulative rain rate distributions for various integration times and data periods and on the variety relationships of lowest (occurrence time) percentage of cumulative rain rate distribution versus data period. From the outlines of analysis results, the regularity of lowest percentage distributions can be classified into (1)ordinary (Fig. 1) and (2)quasi-ordinary (Fig. 2). With the knowledge of the lowest percentage distributions, which integration times are more than 1 hour, to develop a method for estimating such distributions of integration times being less than 1 hour is possible and necessary for the further employment.

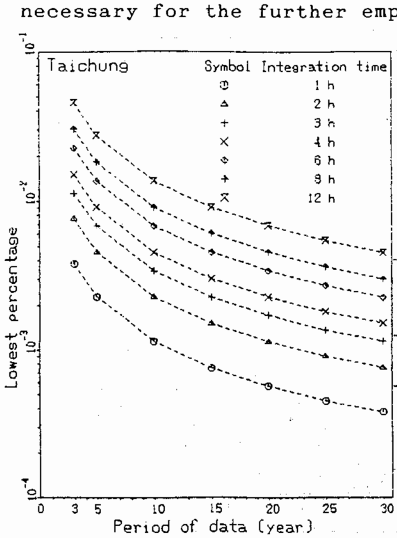

Fig. 1

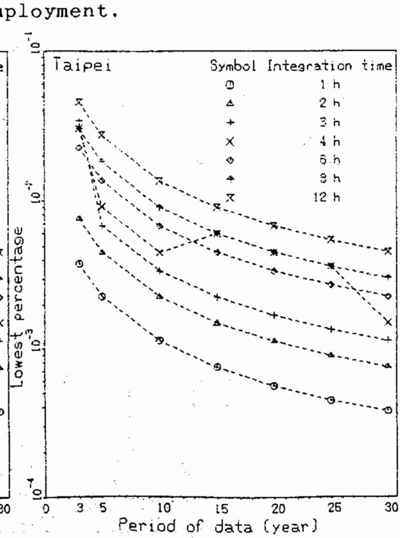

Fig. 2

INTER-ANNUAL VARIATION IN PRECIPITATION CLIMATE

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This paper examines the magnitude and form of the year to year variability in precipitation climate using detailed rainfall observations from stations situated from coast to coast. Statistical resampling methods are used to merge data for locations within uniform climatic regions in order to produce larger samples than any that have previously been examined. Various statistical analyses are employed to establish the precise nature of the inter-annual variation of rainfall intensity.

The paper will describe some of the unique aspects of the methodology employed and discuss the significance of the results in terms of the inherent variability in microwave link attenuation relative to the long term mean.

INITIAL RESULTS FROM A ONE-YEAR SLANT PATH RAIN PROPAGATION EXPERIMENT USING RADAR AND SATELLITE BEACON DATA

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Bradley Department of Electrical Engineering
Virginia Tech
Blacksburg, VA 24061

The data from a one-year experiment conducted at Virginia Tech during 1985-86 have been processed. This paper presents some initial results and conclusions.

The experiment was quite involved. The main component was an S-band multiple polarization radar that was scanned to collect rain scatter data for several earth-space slant propagation paths. Simultaneously, two INTELSAT-V 11 GHz beacon receivers were operating, one at the radar site and the other 7 km distant, simulating a site-diversity system. Rain monitoring equipment was also used. During the one year period the system was operational 87% of the time and recorded 71 significant rain events in which slant path attenuation exceeded 1 dB.

The radar measured both reflectivity (Z) and differential refectivity between vertical and horizontal polarizations (ZDR). These measurements were used in an inference algorithm to estimate the rain drop size distribution in each radar range cell. This information was then used in a forward propagation algorithm to predict earth-space link performance for various paths, frequencies, and elevation angles. These results will be reported as well as other conclusions concerning the precipitation observed.

To validate the results, radar-predicted attenuation statistics at 11.45 GHz were compared to direct beacon measurements. Agreement was very good. Predicted and measured diversity gain for the two receiving sites also agreed.

Thursday PM

Joint AP-S, URSI-A Session 81

RCS MEASUREMENT

Chairmen: J. Young, OSU; V. Liepa, University of Michigan

Room: Schine 304A *Time*: 1:25-5:00

PREDICTION OF THE ERROR DUE TO DISTANCE IN THE MEASUREMENT OR CALCULATION OF ELECTROMAGNETIC BACKSCATTER

J.A.G. Malherbe and C.W.I. Pistorius

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In the measurement of electromagnetic backscatter, the criterium of separation between the observer and the target is usually taken to be somewhere between $2D^2/\lambda$ and $4D^2/\lambda$. This distance corresponds to a prescribed phase error that will ensure an acceptable error in the measured or calculated backscatter. At millimeterwave frequencies it is often impossible (and impractical) to satisfy these criteria, because the target is never that far away from the observer.

It has been shown (Malherbe and Pistorius, Electron. Letters, to be published) that in the case of a two-dimensional target, the error made in assuming that the target is at infinity, is described by a Fresnel integral, and that the argument of the integral is the so-called numerical distance to the target, which includes information on the target size, the frequency and the distance.

In this paper, the two-dimensional limitation has been removed, and expressions for the effect of distance on the measured or computed backscatter for (a) a rectangular flat plate and (b) a circular flat plate have been derived. The derivation is based on a physical optics assumption, i.e. that the currents induced in the surface is just double the incident magnetic field, although the latter varies in phase due to the incident path lengths being different. In the case of the flat plate , the expression for the error is of the form of the product of two Fresnel integrals, while for the round disk, the error is given by a sinx/x-function.

The theory has been verified by measuring the backscatter from a round and a rectangular plate, and experimental results will be present.

A Comparison of Sphere and Small Square-Plate Trihedrals as Compact Range Scattering Calibration Targets

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Columbus, Ohio 43212

A common practice in compact range scattering metrology is measurement of a reference target whose backscattering is stable with respect to orientation and is accurately predicted by theory. The two most common targets used for this purpose are probably the sphere and trihedral. The advantage of the sphere is that its scattering is independent of orientation, and its scattering is predicted with absolute accuracy regardless of frequency. The advantage of the trihedral is that its backscattering is much stronger than the sphere for a comparably sized target, and it interacts less with the support structure and the room.

This paper presents diagnostic scattering measurements of both spheres and trihedrals made in the OSU Compact Range. The results are compared to theory, and the strengths and weaknesses of both are demonstrated. A decision rule for selection between these targets based on measurement frequency, accuracy requirements, support structure characteristics, and cross-section range of the other test targets to be calibrated is presented.

Flat Plate Measurements of Ceiling and Side Wall Scattering in a Compact Radar Scattering Range

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The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
1320 Kinnear Rd.
Columbus, Ohio 43212

One problem of concern in compact ranges is the energy which is scattered off of the walls and ceiling (with their imperfect absorber) into the target region. Assuming such scattering can be measured, the next question is how such energy would cause errors in "real" scattering measurements. This paper discusses a proposed standard experiment for compact range diagnostic testing to provide a worst case answer to these questions.

A tiltable flat plate metal reflector 6 ft. square was positioned in the "sweet spot" of the ElectroScience Laboratory Compact Range, and angled to illuminate several patches of ceiling and walls. Then calibrated frequency-domain signatures were measured, and transformed into bandlimited impulse responses. Knowing the geometry of the target and room permits the impulse responses to be interpreted so that the wall scattering can be compared to the edge scattering and corner backscattering of the tilted plate.

Results to be presented include spectral and impulse responses for the wall and ceiling terms. These data are worst case in the sense that a plane wave reflected beam is pointed at the ceiling or wall, which is stronger illumination than would come from normal quasi-convex targets.

MEASUREMENT PROCEDURES FOR TARGET SCATTERING MATRICES IN BOTH MONOSTATIC AND BISTATIC ARRANGEMENTS FOR THE COHERENT AND PARTIALLY COHERENT CASES

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Alexander B. Kostinski and Wolfgang-M. Boerner
Communications Laboratory (M/C 154)
Department of Electrical Engineering & Computer Science
University of Illinois at Chicago, Chicago, IL 60680-4348

The measurement of the monostatic and bistatic scattering matrices does not only depend on equipment parameters such as polarization state switching, antenna polarization purity, decoupling of co/cross-polarized channels, pulse repetition rate, measurement duration, etc., but more so on environmental factors such as scattering center decorrelation times along the propagation path and on the moving/fluctuating targets. Thus the decorrelation factors and the associated coherency parameters need to be established first, and in case the degree of polarization is less than one, a coherency matrix or [4x1] Stokes vector approach using the 4x4 Mueller matrix representation instead of the [2x2] scattering matrix is strictly required.

Based upon the correction of the pertinent sections of existing standards, we provide a correct formulation of the associated polarimetric radar equations together with a well-defined and consistant procedure for measuring target scattering matrices in both monostatic and bistatic arrangements for a general elliptical polarization state basis pair, for both the coherent and partially coherent cases.

Broadband Time-Domain Antennas

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Electromagnetic Fields Division
National Bureau of Standards
Boulder, CO 80303

The purpose of this paper is to discuss various sensors and radiators commonly used for time-domain antenna measurements. The sensors and radiators discussed here are passive analog devices that convert the electromagnetic quantity of interest to a voltage or current at their terminal ports. Moreover, they are primary standards in the sense that their transfer functions can be calculated from their geometries and are flat (frequency-independent) across a wide frequency range. One of the major requirements of these sensors and radiators is that the electromagnetic far field, for transmission or reception, be a replica or high-fidelity derivative of the original pulse.

Because of their usefulness in electric-field strength measurements, linear antennas nonuniformly and continuously loaded with resistance, or both resistance and capacitance, are discussed. Also, a conical antenna and an asymptotic conical antenna are examined from the standpoint of improved antenna characteristics. Various types of transverse electro-magnetic (TEM) horns are considered for improved directivity, e.g., a conducting TEM horn and a resistively loaded TEM horn. For magnetic-field strength measurements, a loop antenna with uniform resistive loading is discussed.

USE OF GATED TIME DOMAIN RESPONSE IN ANTENNA AND RCS MEASUREMENTS

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National Research Council/
MPB Technologies
Ottawa, Canada

Modern network analyzers and superior data processing abilities of desk top computers have revolutionized the way antenna, radar cross section (RCS) and e.m. field measurements are performed. Built in features such as relatively fast measurements in frequency domain over a large bandwidth, and almost real time conversion of this data to display simulated time domain impulse response provides unprecedented abilities for studying e.m. wave interaction mechanisms. Further data processing permits separating responses in time domain (time domain gating) and reconvertion of these filtered or gated time domain responses back to frequency domain. This allows studying frequency domain response due to isolated "desired" e.m. interaction. These schemes have found to be very useful antenna and RCS measurements in suppressing the effects of multipath and other undesired reflections. However, caution is necessary in using advanced features of modern equipment otherwise the recorded data may not be an accurate measure of the reality.

This paper will describe some of the applications of time domain response in studying e.m. wave interaction. Examples include effect of material and geometric characteristics (such as finite ground plane, curved surfaces etc.) on antenna impedance and inter-antenna coupling. In particular effect of gated time domain response in improving accuracy of antenna and RCS measurements will be described. Some of the errors caused by improper selection of gates, gate widths, and system bandwidth and their effect on measured parameters will be discussed. Some necessary precautions for meaningful measurements using time domain gating will be outlined.

FAR ZONE PATTERN MEASUREMENTS AND TIME DOMAIN ANALYSIS OF REFLECTOR ANTENNAS IN THE COMPACT RANGE

R.C. Rudduck, K.M. Lambert and T.H. Lee
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
1320 Kinnear Road
Columbus, Ohio 43212

The direct far field pattern measurement of an aperture antenna becomes more difficult as the size of the aperture increases. Recent measurements on reflector antennas with $2D^2/\lambda \approx 1500'$ at The Ohio State University ElectroScience Laboratory have demonstrated the usefulness of the compact range in obtaining the complete far field pattern of antennas with large far field distances.

The measurements were performed at 11 GHz on reflector antennas having 8′ diameter apertures. The measurements took advantage of the rolled edge modification of the compact range reflector which allows the target zone to accommodate an antenna under test of this size. Additionally, the pulsed/CW radar of the compact range facility was implemented to provide 80 dB of dynamic range by eliminating the clutter originating from the finite dimensions of the range.

The measured patterns are compared to patterns calculated by The Ohio State University Reflector Antenna Code. The quality of the measured patterns and the good agreement between the measured and calculated patterns demonstrate the utility of the compact range facility for antenna measurements.

The time domain analysis involves taking stepped frequency measurements at fixed pattern angles and then performing the Fourier transformation to the time domain. This technique results in the ability to analyze separately the various radiation and scattering mechanisms associated with the reflector. These include the contributions from the reflector rim, the feed aperture, strut scattering and multiple interactions.

MEASUREMENT AND ANALYSIS OF TRANSIENT EFFECTS IN LOADED ANTENNAS

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S.R. Cloude*,
Dept. of Mathematics and Computer Science
The University, Dundee, DD1 4HN, Scotland

Abstract

This paper details a comparison of methods available for the time domain modelling of transient effects in loaded wire antennas and presents experimental validation of the predictions obtained from these models for the current induced at the base of a monopole antenna loaded by linear and nonlinear circuit elements.

Two theoretical models are compared; a direct time domain solution of Hallen's integral equation for the antenna current and a second based on a frequency domain Norton equivalent circuit for the antenna which leads to a nonlinear Volterra integral equation for the unknown load current. The former is restricted to straight wire antennas and involves recalculation of the current along the whole wire for changes in point loading while the latter is more computationally efficient, requiring no recalculation of antenna current for changes in load conditions.

An important aspect of this work is an experimental validation of the theoretical models. Towards this end, predicted and measured load current waveforms are presented and compared for linear resistive, capacitive and transmission line loading of a monopole mounted above a perfectly conducting ground plane. The transmitting antenna is a coaxial fed bicone transmitting an approximately Gaussian pulse with full width at half height of 160ps at a PRF of 1KHz. The monopole is connected to low loss 50Ω coax with circuit elements placed either directly at the base or, in a screened box, at some convenient distance from the base point. The circuit current is then fed by 50Ω coax to a wideband digitising scope and offline computer for further analysis.

As an important example of nonlinear circuit behaviour, we consider and compare the predicted and observed response of resonant circuits with semiconductor diode loading and demonstrate the significant role played by semiconductor dynamics in determining transient response.

Notes

Thursday PM

URSI-B Session 82

ANTENNA THEORY

Chairmen: A. Adams, Syracuse University;
N. Goto, Tokyo Institute of Technology
Room: Schine 304C *Time*: 1:25-5:00

A LINEAR PHASED ARRAY OF PERIODIC PRINTED-CIRCUIT LEAKY-WAVE LINE SOURCES THAT PERMITS WIDE TWO-DIMENSIONAL SCAN COVERAGE

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Polytechnic University
333 Jay Street, Brooklyn, NY 11201

Two members of a class of two-dimensional scanning arrays for millimeter wavelengths were described recently (A. A. Oliner and S. J. Xu, URSI Abstracts, p. 139, Blacksburg, VA, June 1987, and P. Lampariello and A. A. Oliner, Proc. European Micr. Conf., pp. 555-560, Rome, Italy, Sept. 1987) that consisted of a linear phased array of leaky-wave line sources. These line sources were made *uniform* longitudinally to provide structural simplicity, but as a result the scan in elevation was restricted to the major part of the forward quadrant; the two-dimensional scan provided by the whole array then covered only half of space at best.

The leaky-wave line source in the array analyzed and discussed here is *periodic* rather than uniform longitudinally, containing a periodic array of metal grids or slits. The periodic grid is still simple in configuration, and it can be fabricated at one time by lithographic means, where the mask for such fabrication can incorporate the tapering of the longitudinal aperture distribution for sidelobe control. Since leakage from this periodic grating is provided by the $n = -1$ space harmonic, the angular coverage in elevation would then comprise the whole backward quadrant and some or all of the forward quadrant, depending on the parameter values. The new array therefore permits much wider scan coverage.

This new array was analyzed by employing a unit-cell approach, which takes into account all mutual coupling effects. An accurate transverse equivalent network was developed for this unit cell, in which the result for the constituent metal grating on a dielectric layer was derived via a small-argument solution for the relevant integral equation.

In addition to its relative simplicity in struture, the array has the important advantages of negligible cross polarization (it is horizontally polarized), no grating lobes, and no blind spots. The paper describes the array structure, the principal aspects of the analysis, and the key performance features.

Synthesis Techniques for Circular Arrays

Karl J. Moeller and Vaughn P. Cable*
California Microwave, Inc.
Woodland Hills, California

The characteristics of an open, circular array of antenna elements in free space have been investigated. With the main beam in the plane of the array (endfire), calculated antenna patterns reveal an elliptical beam cross-section, broad in the vertical plane, with high near-in sidelobes. A Taylor-like amplitude distribution was found to reduce the near-in sidelobe level in the horizontal plane without significantly degrading the vertical plane pattern. Reduced near-in sidelobes in the vertical plane are then obtained by either stacking multiple rings of circular arrays or by selection of specific element factors.

Two synthesis techniques, a perturbation technique taken from linear array theory and an optimization technique for uniform sidelobes, have also been investigated. The effects of mutual coupling for these synthesized patterns for an open circular array of dipoles is discussed.

A Highly Steerable and Directional Array Factor

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and
Center for the Engineering of Electronic & Acoustic Materials
The Pennsylvania State University,
UNIVERSITY PARK, PA 16802.

As per the principle of pattern mutiplication, the radiation characteristics of an array of identical radiators can be adequately expressed in terms of the characteristics of a single radiator as well as an array factor, provided it is assumed that the antennas do not interact with one another. For highly directional arrays, feeding the individual elements with differing phases offers potentially significant advantages, and numerical techniques are used to design the feed system in order to achieve substantial sidelobe-reduction. In the process, or through other means, some amount of electronic steerability is also obtained.

The Connell sequence was proposed in 1959, and it has been utilized by us to construct array factors which offer a high degree of directivity as well as steerability by adjustment of the individual phases by a single parameter. The adjacent elements are spaced half-wavelength apart, and the array consists of $q(q+1)/2$ elements, $q > 1$. The phase of the n-th ($n = 1,2,3,...$) element is given by $\exp[ip\varphi_n]$, where

$$\varphi_n = 2\pi\, u_n/U_q,$$

$$U_q = q(q-1)(3q^2 - q + 4)/12,$$

$$u_n = 2n - [\{1 + \sqrt{(8n - 7)}\}/2],$$

and $[x]$ denotes the integral part of x. The parameter p is the control and varies over the range $\pm P_q$, corresponding to which the mainlobe direction also varies continuously. The relationships of P_q and of the array performance to the parameters p and q have been numerically explored, and will be presented.

Thin Insulated Antenna Theory

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Albuquerque, NM 87185

The conventional wisdom for treating the insulation on antennas/cables is "Use the bare antenna theory whenever the antenna does not have insulation, and the insulated antenna theory whenever an insulation layer is present." This paper examines the validity of this statement by studying the limit as the insulation layer approaches zero. This thin insulated antenna theory differs from the conventional theory; in that, it assumes the same condition as the bare antenna theory, whereas the conventional theory requires an additional condition, $|k_4| >> |k_2|$, where k_4 and k_2 are the wave number of the medium and the insulation, respectively. The thin theory also tracks the pole of the exact layer solution in the limit as the insulation disappears. Discussions include: (1) differences between the insulated antenna and the bare antenna in the infinite case, (2) semi-infinite solutions, and (3) approximate, finite-length solutions.

MULTIPACTOR BREAKDOWN IN A CROSS-DIPOLE FEED

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Ste-Anne-de-Bellevue
Quebec
Canada H9G 1E5

This paper describes a theoretical invesigation on multipactor breakdown of a high power cross-dipole feed element. The study also suggests dimensions for a feed which can handle 600 Watts power with more than 6 dB margin. Multipactor breakdown is a secondary electron resonance breakdown. The effect of multipactor breakdown occurs in microwave components carrying high power in a space environment. Multipactor occurs in a situation where a free electron is accelerated toward a surface under RF voltage. Upon impact, a number of secondary electrons are released which in turn act as bombarding electrons in the reverse cycle of the RF signal. As this process continues, the electron population rapidly increases to the point where breakdown occurs.

NEAR FIELD CALCULATIONS FOR A HIGH POWER HF DIPOLE CURTAIN ARRAY

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Horizontal dipole curtain arrays are used as broadcast transmitting antennas for long-range transmission at high frequencies (HF). Dipole curtain array is a rectangular array of horizontal dipoles usually half wavelength long, mounted in front of a reflecting screen. Since the transmitted power can be very high (of the order of 1 MW), it is important to estimate the field strength contours in near-field region very close to the ground plane.

In order to accurately estimate the field strength in the near-field, one needs to consider the complete current distribution over the curtain array as well as the effect of the ground plane. The reactive components of the fields need to be considered, when the field point is less than a wavelength from the array. Since the above procedure becomes quite complicated, an approximate method which has been used to give conservative estimate of the actual field strength, will be outlined.

In this method, the array has been reduced to a point source located at the radiation center of the array, having the radiation pattern and gain of the entire array. The far-field equations are used. The earth is considered to be flat and perfectly conducting. The field is assumed to be inversely proportional to the shortest horizontal distance between the source and the field point. The direct and ground reflected fields are added at the near-field point, by approximating the phase difference between the fields for low height of the field point. The reflecting screen is assumed to be geometrically identical to the main array. It can be shown that all the above approximations will result in conservative estimate of the field strength, thereby predicting the worst case scenario. Typical contours will be shown and estimates of errors associated with different approximations will be discussed.

TRUNCATED SPHERICAL PROBING

Sembiam R. Rengarajan [1]
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Spherical Wave Expansion has been widely employed in antenna analysis and measurement applications. Jensen and Larsen (IEEE A.P. Symposium Digest, pp. 378-381, 1977) showed that by truncating the near field probing region, it is possible to compute far fields accurately within the region of interest. In this paper, truncated spherical probing of aperture antennas and reflectors is addressed. Numerical results on reconstructed radiation patterns in the near field and far field regions are presented. The effect of truncation on the spherical mode coefficients and gain are investigated. Near fields reconstructed from truncated spherical far field probing of hyperboloids / ellipsoids have applications in the analysis of Cassegrain / Gregorian reflectors. Results presented for truncated near field probing cases are useful in spherical near field measurements.

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[1] on sabbatical from California State University, Northridge.

THE EFFECT OF FINITE GROUNDPLANES ON THE RADIATION PATTERNS OF SMALL SLOT ARRAYS

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D.A.McNamara, Univ. of Pretoria, Pretoria, South Africa

The slotted waveguide array is a widely used antenna. A considerable amount has been published on reliable procedures (R.S.Elliott, IEEE Trans., AP-31, 48-53, Jan. 1983) for the design of such arrays. However, accurate prediction of the radiation patterns of such antennas, taking into account the effects of the finite groundplane in which the slots are mounted, has received less attention in the literature. A knowledge of the effects of the groundplane on the pattern sidelobes, especially in the case of low sidelobe arrays, would greatly increase the designer's confidence.

In this paper the geometrical theory of diffraction (R.G.Kouyoumjian & P.H.Pathak, Proc. IEEE, 62, 1448-1461, 1974) has been used to include the groundplane edge diffraction in the pattern computation. A slot is represented by a magnetic current source. At each point in space the far-zone fields of each slot in the presence of the groundplane are found as the sum of a direct ray and several diffracted rays. The overall pattern is then the sum of that obtained for each slot/groundplane combination individually. For each slot, and for each different pattern cut, there will be different diffraction point positions; these stationary points are easily found using the law of diffraction (R.G.Kouyoumjian & P.H.Pathak, Proc. IEEE, 62, 1448-1461, 1974). Three different array groundplane shapes are considered : rectangular, elliptical and circular. For the elliptical groundplane there are in general four diffraction points (this reduces to two in the case of the circular groundplane), while there are two such points for the rectangular case. In the latter case corner diffraction is included (W.D.Burnside et. al., IEEE Trans., AP-28, 318-327, 1980).

Results of a parametric study conducted using the above analysis will be presented. Firstly, the effect of the rectangular groundplane size on the sidelobe levels of a linear slotted waveguide is given. Then a planar array of 32 elements (the typical size of a small slotted waveguide array) is considered, and the patterns with the above-mentioned three shapes of groundplane (of various sizes) are compared as regards their "sidelobe performance" advantages and disadvantages. Computed results are compared with measured patterns where available.

A SYNTHESIS METHOD FOR CIRCULAR ARRAYS USING SPATIAL MODES EXPANSION

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This work describes a pattern synthesis process for circular arrays whose radiating elements are arranged with radial symmetry. This is a general procedure based in the expansion in spatial modes of both the whole array radiation pattern and its radiating elements with their respective phases. These two expansions are related through the excitacion coefficients to match the pattern specifications.

These expansion series have to be truncated and this becomes the main constraint of the method. If the separation between the elements is less than half the wavelength, the approximation proves to be reliable. On the other hand, if the array radius is too small, this method also generates the excitacion coefficients, but the resulting values lead to a super-gain effect that makes the practical realization hardly feasible.

This procedure has been applied to Chebycheff and Taylor patterns constructed with very simple radiating elements. Within the valid margin previously mentioned, the results were fully satisfactory. It has been proved that the synthesis is reliable even with patterns having extremely reduced sidelobes and it has been applied to semicircular arrays with similar results.

Windowing and error minimization techniques may be used to spread the truncation errors along the whole pattern. A slight margin extension has been achieved using some of these techniques in the computer simulations performed during the tests.

This procedure can be carried out with any other kind of pattern with the help of conventional techniques for linear arrays synthesis.

Thursday PM

URSI-B Session 83

REFLECTOR ANTENNAS IV

Chairmen: V. Galindo, JPL; A. I. Zaghloul, Comsat Laboratories

Room: Newhouse A2 *Time*: 1:25-5:00

EDGE-TREATED COMPACT RANGE REFLECTORS

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Recent studies have demonstrated that rolled edges blended into a parabolic dish can improve the performance of a compact range reflector by reducing the amplitude and phase ripple in the quiet zone (W. D. Burnside, et. al., IEEE Trans. Antennas Propagat. AP-35, 2, 176-182, 1987). Rolled edges greatly reduce diffraction directly into the quiet zone, but can enhance scattering in the direction of walls and fixtures, thus imposing undesirable constraints on the measurement chamber.

In this investigation, we examine the effectiveness of edge treatments on compact range reflectors, both in optimizing the quiet zone and in reducing the stray fields elsewhere. As a baseline configuration, a parabolic half-dish is chosen with a blended rolled edge to which tapered dielectric treatment is added. Because of the accuracy requirements, a method-of-moments-based mixed-domain Galerkin formulation is used to compute the near fields (amplitude and phase) at the critical lower frequency limit of the reflector. A mapping of the edge currents is obtained to provide physical insight into the problem. The reflector-test target interaction effects are also examined for various size targets at varying field points.

PROBLEMS AND SOLUTIONS FOUND IN THE DESIGN AND ANALYSIS OF WIRE MESH REFLECTOR ANTENNAS

Dr. William Imbriale, Dr. Victor Galindo-Israel,
and Dr. Yahya Rahmat-Samii

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Wire mesh knit reflecting surfaces are now frequently used on unfurlable type spacecraft reflector antennas (TDRSS, Galileo, etc.). The knit characteristic of this mesh permits the surface to be stretched and tied so that a smooth doubly curved surface is obtained with minimal pillowing. The knit is essentially a thin periodic (or nearly so) surface. Each periodic cell consists of a complex "weave" of very fine wires.

The fineness of the wires and the complexity of the weave has made the problem of an exact numerical diffraction analysis quite formidable. We have successfully analyzed this mesh by treating it as a flat weave of wire strips in a periodic array. The analysis is by moment methods using a piece-wise triangular basis function with a Floquet mode analysis of the periodic structure. In particular, we have found that wire bends and junctions can be properly treated only if precise and careful attention is paid to the vector continuity of current through the wire strip bend or junction.

It is common in some fine wire mesh grids to avoid soldering the junctions of wires and to depend upon contact pressure in order to obtain good electrical continuity at junction points. Under certain conditions, as has been found experimentally, poor electrical contact in these mesh surfaces can result in poor surface reflectivity and considerable transmission loss. The poor surface reflectivity of the tricot knit mesh has been verified by analysis for the case when there is no electrical contact at the junction points. In addition, a simple model of the tricot mesh which provides an understanding of the cause of the poor reflectivity is presented. Alternative knit models for avoiding these problems are thus indicated.

ANALYSIS OF REFLECTOR ANTENNAS USING INCREMENTAL DIFFRACTION COEFFICIENTS

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Incremental diffraction coefficients (IDC's) provide a powerful technique for enhancing the accuracy of reflector antenna patterns obtained from physical optics (PO) currents. Unlike other techniques employed for taking into account scattering from edge discontinuties of reflectors (e.g., GTD, PTD), the integration of IDC's yields corrections to the PO fields that are valid in virtually all ranges of the pattern angles and so obviates the necessity of employing a number of distinct formulations corresponding to different ranges.

In this paper we demonstrate two applications of IDC's. First we use the IDC's for a half-plane to calculate the correction to the PO reflector pattern of the nonuniform current near the rim of the reflector. The antenna is assumed to be focal-fed with either an electric dipole or a Huygens source. Patterns obtained with a computer program that integrates the IDC's along the rim of the reflector are shown to agree closely with those calculated by Bach and Viskum (IEE Proc., Aug. 1986, IEEE AP-S Trans., Feb. 1987) using the method of moments applied to an electric field integral equation. The back lobes of the co-polarized reflector patterns in the principal plane, and the cross-polarized field are significantly affected by the rim-diffracted field.

We then use the IDC's for a narrow slit to study the effect of cracks in the surface of reflector antennas such as those formed by the imperfect fitting together of panels to form large reflectors. The antenna is assumed fed by a Huygens source at the focus, and both azimuthal and radially directed cracks are considered. The effect of the cracks is obtained by numerical integration of the slit IDC's along the cracks. The cross-polarized field is especially strongly modified by the inclusion of the slit-diffracted fields. It is found that the method of IDC's is considerably more effective and convenient to use than conventional asymptotic high frequency techniques for obtaining the modifications of the PO pattern due to the cracks in the reflector surface.

GLOBAL SURFACE EXPANSION COEFFICIENT OPTIMIZATION FOR REFLECTOR SHAPING

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In modern satellite antenna systems, contour beam generation, multiple beam formation, and spot beam creation are finding numerous applications. Customarily, these design objectives are achieved using offset parabolic reflector antennas with array feeds in the focal plane of the reflector. The concept typically requires a sophisticated beam forming network. Recently, attention has been focused on designs using a single feed element (or elements), with no sophisticated beam forming network, that still achieve the design objectives. Attempts have been made to utilize non-parabolic reflector surfaces that produce the desired performance. Several methodologies have been used in the recent past, however, most of them do not lend themselves in a systematic way to surface profile generation in conjunction with diffraction considerations.

In this paper, results of surface shaping for improved performance is reported. The concept of global surface coefficient optimization is used. In this technique, the reflector surface (or surfaces) is expanded in terms of unknown coefficients using global Fourier-Jacobi orthogonal polynomials. The question is then: how to find these unknown coefficients? An optimization procedure based upon the Levenberg-Marguardt algorithm is used to determine the unknown coefficients by implementing a diffraction analysis evaluation of the antenna performance at each stage of the optimization. The optimization cost function is defined such that it satisfies the design objectives of the problem at hand.

Many numerical results will be shown to demonstrate the utility of the concept for several different cases. The effects of the cost function selection, starting surface profile, and number of expansion coefficients will also be presented. One of the advantages of the global expansion optimization technique is that it directly utilizes curved reflector surfaces; hence, after the coefficients are determined they can be used directly in the diffraction analysis of the reflector pattern. Furthermore, there is no need to use an interpolation algorithm to characterize the reflector surface as typically needed in other surface shaping approaches which are based on the geometrical optical shaping or aperture distribution shaping.

FOCAL REGION FIELDS OF REFLECTOR ANTENNAS WITH ARBITRARY SURFACE DISTORTIONS

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Surface distortions of reflector antennas result in severe effects on their performance. In certain environments, surface distortions may be too difficult to correct on a functioning antenna. This is the case, for example, of the large space deployable antenna. In these cases, surface distortion effects may be compensated by appropriate feed tapering. In the spirit of these efforts, the focal region fields are needed of reflectors that suffer from arbitrary surface distortions. In this paper, we present results of an algorithm developed to analyze the fields scattered by arbitrarily shaped conductors. The surface of the conductor is specified by the coordinates of a set of target points. Using a max-min criterion, the aperture of the reflector is discretized in a set of triangular domains with vertices being the projections of the target points on the aperture plane. In each domain the surface of the reflector is interpolated by a fifth degree bivariate polynomial and the current induced on the surface is calculated for certain incident fields according to the PO approximation. The total scattered field is calculated by adding up the contributions from each triangular domain. An appropriate modification of Gaussian Quadrature is used for the numerical integration of the integrals involved in the field expressions. Several results are presented for parabolic reflectors with distortions. Surface distortions effects on co-pol and cross-pol fields are discussed.

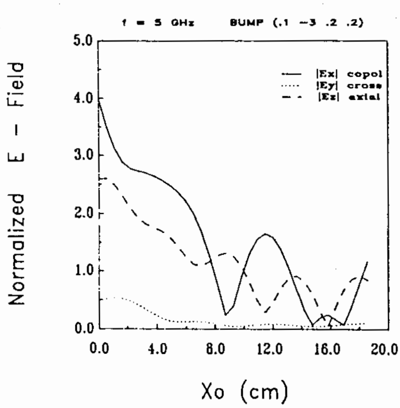

Figure: Fields scattered by a D = 2m, F = 1.19m parabolic reflector with a bump. The incident field is a plane wave along the optical axis.

PERFORMANCE COMPARISON OF HOPPING AND SCANNING BEAM SATELLITE ANTENNAS

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Competition with optical fibers will require that future satellite systems deliver enhanced services such as point to multipoint communications and ultimately provide direct services to end users. These services will be implemented by satellite systems that employ SS/TDMA via fast hopping or scanning spot beams over the earth. (Zaghloul, et al., 1987 MILCOM). In a hopping beam system each spot beam corresponds to one feed element or a cluster of feeds and the beam movement is achieved by shifting the power from one feed element or one cluster to another. The beam selection of these systems is accomplished by using a switch matrix network. In a scanning beam system the beam is generated by controlling the phase distribution across the antenna aperture and thereby all elements contribute to each scanning beam.

This paper presents a comparison between four different optical configurations for the hopping and scanning beam antennas. The single offset parabolic reflector is the simplest for hopping beam applications. Large reflector size and focal length are required, however, to produce the desired co and cross-polarization isolations. Dual reflector systems offer an attractive alternative. Side-fed offset Cassegrain (SFOC) system (Jorgensen,et al., IEEE/AP Trans.,1985) is chosen as the second hopping beam configuration because of its low scan loss, compatibility with large feed arrays and large effective focal length which leads to high co and cross-pol isolations for the same size of the main reflector.

Two scanning beam antennas are considered, near-field Gregorian reflector fed by an active phased array and a direct radiating active phased array (DRA). The near field Gregorian optic can be employed to magnify a plane wave excitation and thus provide a potential reduction in weight and complexity versus DRA. However, as the magnification of the optics is increased the radiation performance relative to the DRA can degrade through increased scan loss and decreased cross-pol isolation.

A comparison between the four systems from the points of view of gain, isolation, weight and power estimates for specific beam size and EIRP requirements are presented.

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83-7

SCATTERING FROM PARTIAL SURFACES OF REVOLUTION

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Electromagnetic problems dealing with bodies of revolution (BORs) have been the subject of extensive investigations using a variety of classical, analytical, and more recently, numerical methods. When the Galerkin technique is used with a harmonic circumferential expansion along ϕ, there is modal decoupling in the integral operators. (J. R. Mautz and R. F. Harrington, AEU **32**, 159-164, 1978; P. L. Huddleston et al. AP-34, 510-520, 1986.) This coupling is true for conducting as well as for penetrable surfaces or bodies. This highly desireable mathematical property is lost if the problem lacks rotational symmetry.

This paper examines classes of partial surfaces of revolution in the presence of perfectly electrically or magnetically conducting (p.e.c. or p.m.c.) image planes where modal decoupling is preserved by a judicious choice of circumferential basis functions. As an application of the general formulation, a class of surfaces is examined in the context of reflectors in a compact range. The effect of edges on the near-field behavior of these reflectors is discussed.

A NEW LOOK ON SHAPING ROTATIONALLY SYMMETRIC REFLECTORS.

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Universidad Politécnica de Madrid.

This paper describes the design of the E.S.A. TMS-7 (moving ground station) antenna for 20-30 GHz communications with the Olympus satellite. The baseline design was of the classical Cassegrain type for mechanical stiffness.

The blockage of the subreflector and the struts makes it difficult to obtain a side lobe envelope compliant with the CCIR specification. A simplified model of the effects of the subreflector and struts blockage and diffraction, that accounts also for the direct feed spillover, [M.Calvo, J.L.Besada, R.Mompó. "Fast Model for the Pre-design of Dual Reflector Antennas". VI Annual Meeting of the Spanish Commission B of URSI. Valencia Sept 1987] was used to define the baseline reflector geometry, the required aperture illumination, and the conical corrugated horn feed.

The desired aperture distribution (uniform phase and parabolic type amplitude) can be obtained from the amplitude and phase feed pattern by shaping both the subreflector and main reflector. The classical Galindo-Williams shaping technique [Galindo. "Design of Dual Reflector Antennas with Arbitrary Phase and Amplitude Distribution". IEEE TAP. Jul 1964] for rotationally symmetric reflectors was used. However, instead of using the ray path length as a condition, the Snell law of reflection in both reflectors was used. Both procedures are equivalent [Collin. Zucker. "Antenna Theory, Part 2". McGraw Hill. 1969]. This new form of implementing the method is easier to program and allows for a more intuitive interpretation.

The synthetized dual reflector has been analyzed and the results obtained are compliant with the CCIR envelope. The antenna is now under construction and measured patterns will be available soon.

ATLANTIS ANTENNA FOR THE SIMULTANEOUS DBS COVERAGE OF SPAIN AND PORTUGAL.

M. Calvo*(1), J.L. Besada(1), L. Haro(1), B. Galocha(1), C. Montesano(2), E. Vila(2), G. Crone(3).

(1) Radiation Group Polytechnic University of Madrid.
(2) Space Division, CASA.
(3) ESTEC, ESA.

ATLANTIS (Advanced Telecommunication Antenna for Iberia Satellite) is a European Space Agency project for the design, manufacturing and testing of a Demonstration Model antenna intended for the simultaneous coverage of Spain and Portugal Mainland and Islands.

The antenna will consist of an offset reflector with an elliptical aperture of 2.3x3.2 meters ["L.R.A. 11/14". CASA Final Report for ESTEC Contract NO. 5277/82/NL/PP.] fed by a cluster of horns. The required amplitude and phase excitations of the horns will be provided by a Beam Forming Network through corrugated waveguide polarizers to produce the circular polarization.

This work will be focused on the electrical design of the antenna. A parametric study was performed to determine the optimum number of horns and their aperture size and location in the focal plane. We have used for this purpose the COBRA software package from TICRA [R. Jorgensen: "Manual for COBRA Synthesis. Software for Optimization of Multibeam Reflector Antennas". TICRA A/S S-164-03. Copenhagen Nov. 1982.] in the synthesis and analysis of the antenna configurations.

Different types of horns have been considered for the cluster feed. Potter and Turrin types of dual mode horns, as well as fundamental mode TE11 conical ones have been designed, breadboarded and tested. Crosspolarization, frequency band, input VSWR and mutual coupling have been accounted for in the trade-off studies. The Queen Mary College software for mutual coupling [S.M. Tun, P.J.B. Clarricoats, C.G. Parini: "A Computer Package for the Radiation and Mutual Coupling Analysis of a Dominant Mode Circular Horn Array". ESTEC Contract NO 5296/82/NL/GM. April 1985.] and our analysis program based on the Moment Method for Bodies of Revolution [M.F. Cátedra: "User's Manual for the Antenna with Symmetry of Revolution Code (ASRC)". Report UPMT/ETSIT/GR/21/87. July 1987.] were used.

Final antenna configuration with its theoretical performance, predicted from the measured cluster feed patterns, will be presented as the final integration and testing of the whole antenna is foreseen for September 1988.

Thursday PM

Joint AP-S, URSI-B Session 84

SCATTERING & DIFFRACTION - RADAR CROSS SECTION

Chairmen: W. Burnside, OSU; Y. Das, DRES

Room: Newhouse 254 *Time*: 1:25-5:00

1:30	**A Simple Aproximate Technique to Compute Scattering from Finite Cylinders with Arbitrary Cross-Section** J. Frederick, P. K. Murthy, Univ. of Dayton	440
1:50	**Experimental Measurement of the Scattering Patterns of Resistive Sheets** R. L. Haupt, United State Air Force Academy; V. V. Leipa, The University of Michigan	See AP-S Dig.
2:10	**The Disk: A Comparison of Electromagnetic Scattering Solutions and its Use As A Calibration Standard For Bistatic RCS Measurement** K. D. Trott, Rome Air Development Center	441
2:30	**Effect of Multiple Scattering on the Radar Cross Section of Polygonal Plate Structures** R. G. Atkins, R. T. Shin, MIT Lincoln Laboratory	442
2:50	**COFFEE BREAK**	
3:20	**A Rigorous Calculation of Radar Cross-Section of a Circular Cavity on An Infinite Wall** Y. Cho, NASA Ames Research Center	443
3:40	**Cross Range Processing and RCS Data** E. C. Burt, MIT Lincoln Lab	444
4:00	**Distributed Equivalent Dipole Solutions of Three-Dimensional Scattering Problems** H. Shigesawa, M. Tsuji, Doshisha University; M. Nishimura, Maizuru Technical College	See AP-S Dig.
4:20	**RCS of Large Bodies Showing a N-Order Symmetry of Rotation by B.E.M. Computation** P. Bannelier, C. Brochard, J. P. Martinaud, J. Tourneur, Thomson-CSF	445
4:40	**Performance of Thinning Arrays by Exponential Spacings** Y. Zhang, Z. Bao, Northwest Telecommunications Engineering Institute	See AP-S Dig.

A SIMPLE APPROXIMATE TECHNIQUE TO COMPUTE SCATTERING FROM FINITE CYLINDERS WITH ARBITRARY CROSS-SECTION

Joseph M. Frederick
P.K. Murthy
Electromagnetics Group - University of Dayton

The problem of scattering from perfectly conducting finite cylinders of arbitarary cross-section is considered. This is a three dimensional problem and a technique is developed to reduce this 3-D problem to a sequence of 2-D problems. This involves the following approximation: The current at any point on the cylinder surface is taken to be the same as that on an infinite cylinder with the same cross-section. Several well known techniques are available to solve the 2-D problems. The edges, due to the finiteness of the cylinder, may be easily accounted for by the inclusion of equivalent currents. Using the approximate current, so obtained, the scattered fields may be computed.

A finite ogival cylinder with perfect conductivity is taken to be the test case. A model was designed fabricated and far-field radar range testing was carried out. RCS was measured for bi-static angles of 2°, 45° and 90° for several different incident angles and for both TE and TM polarizations. This experimental data was compared to RCS predicted by the approximate model developed here and good agreement is evident. Work is presently in progress to extend this analysis to finite cylinders with gently varying cross-section.

84-3

THE DISK: A COMPARISON OF ELECTROMAGNETIC SCATTERING SOLUTIONS AND ITS USE AS A CALIBRATION STANDARD FOR BISTATIC RCS MEASUREMENTS

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Three solutions for scattering from a perfectly conducting disk are compared: a closed-form Physical Optics (PO) solution, a Physical Theory of Diffraction (PTD) solution, and an exact eigenfunction solution. Far field patterns are compared for various ka values and incidence angles for both horizontally and vertically polarized electric fields. For normal incidence, the PO and eigenfunction solutions agreed very well over the main lobe and a significant number of side lobes. For small ka the agreement is remarkable; however, as ka increases, and the observation angle exceeds 45 degrees, a shift occurs in the sidelobes when the incident electric field lies parallel to the edge of the disk. This shift is not as pronounced when the incident electric field lies perpendicular to the edge.

Applicability of the disk as a calibration standard for bistatic scattering measurements is discussed by examining the calibration curve (specular return). The specular return, as a function of bistatic angle, is computed for both horizontal and vertical polarizations at various ka values using the PO, PTD, and eigenfunction solutions. The calibration curve found using PO goes to zero for both polarizations; however, the calibration curve computed using the eigenfunction solution does not go to zero when the incident electric field is parallel to the edge because it contains the proper edge behavior. The agreement between the solutions is good for bistatic angles out to 140 degrees for ka as low as five. Also, as expected, the agreement for the specular return improves as ka increases.

EFFECT OF MULTIPLE SCATTERING ON THE RADAR CROSS SECTION OF POLYGONAL PLATE STRUCTURES

R. G. Atkins* and R. T. Shin

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Existing radar cross section (RCS) prediction algorithms using the Physical Optics and the Physical Theory of Diffraction techniques have been shown to give erroneous results for cases in which multiple scattering between portions of the target is significant. In particular, double reflections between flat plate surfaces are important for geometries resembling the corner reflector, and this effect is neglected by current algorithms which include only single surface interactions. To overcome this limitation a method is presented of extending the conventional results obtained using Physical Optics to include a field due to double reflections between two polygonal plate surfaces.

An integral expression is derived, applying the tangent plane approximation at each surface, and correctly accounting for the potentially near-field interactions between the two perfectly conducting plates. The initial complexity of this expression necessitates numerical evaluation of the integrals and results in a large computational burden. The requirement of numerical integration is eliminated, however, by applying the method of Stationary Phase and expanding quadratically the exact inter-plate phase term. The two surface integrations are replaced by line integrals using Stokes' Theorem, and for polygonal plates, the contour is subdivided into linear segments on which the integration is performed analytically. In the case where the conducting plates are loaded with one or more layers of dielectric, the equivalent electric and magnetic surface currents are derived using the reflection coefficients at each plate.

The resulting field expressions are derived with sufficient generality so as to permit incorporation in standard RCS prediction codes allowing arbitrary geometry and illumination. Comparisons with measurements of several simple two-plate targets confirm the accuracy of the predicted field and demonstrate a significant improvement over existing algorithms which neglect multiple reflections or which assume a far field interaction between the surfaces.

This work was sponsored by the U.S. Air Force under contract F19628-85-C-0002. The views expressed are those of the authors and do not reflect the official policy or position of the U.S. Government.

A Rigorous Calculation of Radar Cross-Section of A Circular Cavity on An Infinite Wall

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An exact solution is presented for the diffraction of a scalar plane wave by a circular cylindrical cavity on an infinite plane wall. The wave functions are subjected to the boundary condition of vanishing normal derivative on the wall and also on the inner surface of the cavity. At the entrance of the cavity, an incident wave will excite wave guide modes which propagate into the cavity, and will partly be scattered back into free space. The scattered waves will be obtained in terms of hyperboloidal wave functions. These functions are defined as a class of eigensolutions of the wave equation for oblate spheroidal coordinates. The hyperboloidal wave functions are distinct from, and superior to the conventional oblate spheroidal wave functions for problems involving half space, as in the present study. The results will include rigorously calculated radar cross section for various incident angles and frequencies of the incident plane waves. The powers of scattered waves and of waves transmitted into the cavity will be also presented.

Cross Range Processing and RCS Data*

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When analyzing data from measured or predicted RCS patterns it is often desirable to be able to associate components of scattering with specific portions of the target. If the RCS data are coherent, i.e. if both amplitude and phase are available, then it is possible to obtain a cross range profile of the target through use of the Fourier transform. This is essentially Doppler processing and is the same procedure that is used in SAR and ISAR imaging systems, except that in our case the entire target is contained in one range resolution cell. This paper will discuss the use of cross range processing as a method of analyzing measured and predicted RCS data. Comparisons between patterns obtained using PTD and the method of moments will be shown for several targets, together with cross range plots showing the level of agreement at locations across the target.

If the coherent RCS samples are available at a spacing of $\Delta\theta$ in angle, then the unambiguous cross range window is $X_{Window} = \lambda/2\Delta\theta$. If $\Delta\theta$ were chosen to be as large as possible while still resulting in an adequate cross range window, it would be too coarse for most applications — including making a simple plot of the RCS pattern. However, by the Sampling Theorem one can see that these coarse samples contain enough information to allow intermediate RCS values to be reconstructed. This fact can be exploited to allow predicted coherent RCS values to be calculated at relatively coarse samples with intermediate values obtained using interpolation methods related to the Sampling Theorem. For some applications this can reduce the required computer run time by a factor of 5 or more. Examples illustrating this approach will be included in the paper.

*This work was sponsored by the Department of the Air Force. The views expressed are those of the author and do not reflect the official policy or position of the U.S. Government.

RCS OF LARGE BODIES SHOWING A N-ORDER SYMMETRY OF ROTATION BY B.E.M. COMPUTATION

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92242 MALAKOFF-CEDEX, FRANCE

The boundary element method (B.E.M.) has been successfully applied to calculate radiation patterns of antennas using the electric field integral equation under variational form (1,2). This work has been recently extended in THOMSON-CSF to calculate the RCS of arbitrary shape objects involving various metallic surfaces and homogeneous media.

In order to access dimensions of objects substantially large compared to wavelength, a formulation has been developped taking into account rotational symmetry of arbitrary order. The order of rotation N can either be imposed by the geometry (for example the number of blades of a turbopropeller) or arbitrary (in case of circularly invariant structures). The whole structure can be deduced by rotations of a generic cell and its associated mesh.

In case of general excitation (i.e. not admitting the rotational symmetry), the problem is shown to reduce to a linear combination of N sub-problems, each one corresponding to a definite phase difference between adjacent cells. For each sub-problem, the unknowns are only those associated with the generic cell and the electromagnetic quantities on the symmetric cells can be deduced by discrete Fourier transform.

Taking into account the symmetry, the primary problem has thus been replaced by the linear combination of N sub-problems whose number of unknowns is divided by N. This implies the following improvements:

- storage requirements are divided by N/2 (the factor of 2 arising from the fact that matrixes are no longer symmetric),
- the number of electromagnetic interactions to be evaluated between elements of the mesh is divided by N,
- time for solving linear systems is of order NxN smaller.

Several examples will be presented during the conference showing a good agreement with experimental results and the advantages of the method.

(1) - " Finite element approximation of electromagnetic diffraction by arbitrarly shaped surfaces ", A. BENDALI, D. CLAIR, J. TOURNEUR, Electronics Letters 22nd July 1982, vol 18, No 15 pp 641-642.

(2) - " General numerical procedure for conception of metallic and dielectric large bandwidth horns ", C. BROCHARD, J.P. MARTINAUD, J. TOURNEUR, U.R.S.I. Symposium, Philadelphia, Juin 1986.

Notes

Thursday PM

URSI-B Session 85

SCATTERING & DIFFRACTION IV

Chairmen: E. Jull, University of British Columbia;
A. Bhattacharyya, Northeastern University
Room: Newhouse 262 *Time*: 1:25-5:00

SCATTERING FROM LOSSY CASCADED GRATINGS

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ASTRACT

The spectral corrector iteration technique along with the theory of scattering matricies is employed to analyze the scattering from lossy cascaded gratings. The total reflection and transmission coefficients are presented as a function of the angle of incidence. The dependence of the coefficients on various grating parameters such as wire spacing, wire thickness, losses in the wire, grating separation and the number of gratings is presented. The problem of stacked lossy dielectric slabs with periodic gratings is formulated and analyzed. The results obtained are compared with other data published in the literature.

THE NULL FIELD APPROACH TO ELECTROMAGNETIC SCATTERING FROM COMPOSITE OBJECTS: THE CASE OF CONCAVO-CONVEX CONSTITUENTS

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Time-harmonic electromagnetic scattering from a composite body consisting of a (dielectric or metallic) core plus one or several dielectric coatings has been studied by means of the null field approach. Previously developed null field approaches to scattering from composite bodies do not apply when these coatings are of concavo-convex shapes. The present work emphasizes that case and some altermative null field approaches to such geometries are developed. The scattering problem is solved by means of a determination of the total transition matrix, referring to spherical waves, for the composite scatterer. The alternative approaches lead to different algebraic expressions for the transition matrix. The numerical implementation of these formulas to a number of examples shows that useful convergence is obtained for a frequency interval that often extends into the resonance region.

The quality of the results are checked against general constraints such as symmetry and unitarity, as well as against other computed and measured results. Another test concerns the influence on the numerical performance of the choice of expansion functions for the surface fields. In the applications to composite scatterers given here, expansions in terms of vector spherical harmonics is often the preferred choice. As examples numerical results for bistatic and radar cross sections are presented for composite scatterers which consist of a core plus a single-layer coating which consists of two parts which have different dielectric properties. Results which illustrate the resonance structure of radar cross sections for this type of composite scatterer as a function of frequency are also given.

NON-UNIQUENESS OF THE SURFACE EFIE APPLIED TO MULTIPLE CONDUCTING AND/OR DIELECTRIC BODIES

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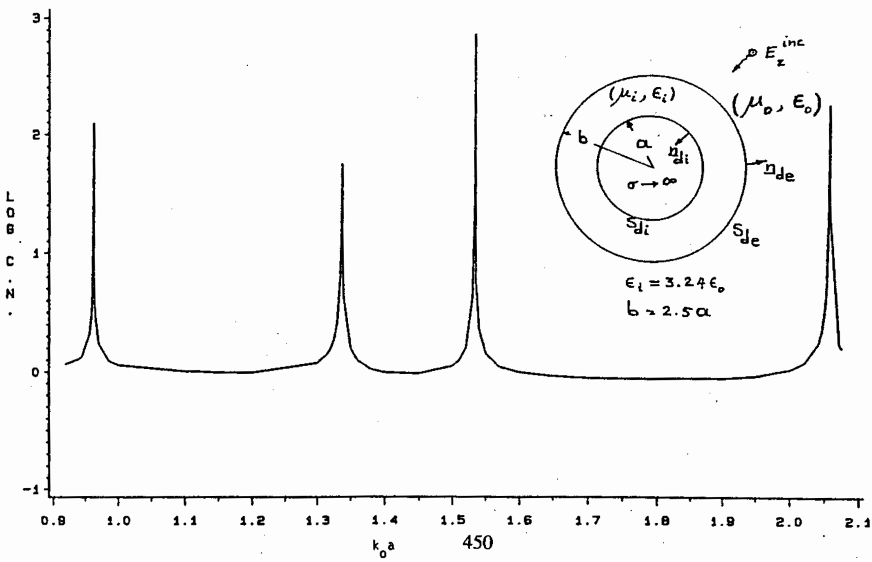
It is proved that the surface electric field integral equations as applied to perfectly conducting and/or homogeneous dielectric bodies do not have unique solutions at certain frequencies. For example, the problem of scattering from a perfect conductor covered by a dielectric layer can be formulated in terms of the following set of coupled integral equations.

$$\underline{n}_{de} \times \underline{E}_e^- (\underline{J}_d , \underline{M}_d) = - \underline{n}_{de} \times \underline{E}^{inc} \qquad \text{On } S_{de}^-$$

$$\underline{n}_{de} \times \underline{E}_i^+ (\underline{J}_c - \underline{J}_d , - \underline{M}_d) = 0 \qquad \text{On } S_{de}^+$$

$$\underline{n}_{di} \times \underline{E}_i^+ (\underline{J}_c - \underline{J}_d , - \underline{M}_d) = 0 \qquad \text{On } S_{di}^+$$

These equations fail to give unique solutions if (i) S_{di} when filled with (μ_i, ϵ_i) and covered with a perfect conductor forms a resonant cavity, or (ii) S_{de} when filled with (μ_o, ϵ_o) and covered with a perfect conductor forms a resonant cavity. The figure below shows the condition number of the moment matrix for a conducting circular cylinder covered by a dielectric layer, and illuminated by a TM plane wave. The peaks occur near the frequencies where the formulation fails.



SCATTERING FROM AN ANISOTROPICALLY CLAD CIRCULAR CYLINDER AT OBLIQUE INCIDENCE

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The scattering of an electromagnetic (EM) plane wave from a circular metallic cylinder coated by a lossy anisotropic layer at oblique incidence is investigated. The anisotropic coating is characterized by tensors $\bar{\bar{\varepsilon}}$ and $\bar{\bar{\mu}}$ which are diagonal when referred to principal axes (ρ, φ, z).

In the biaxial layer, by assuming harmonic axial and angular dependence, a set of coupled second order equations is derived for the axial components of the electromagnetic fields. These equations are solved by standard methods and an exact field expansion is obtained in terms of special cylindrical functions.

Calculated far scattered field for the aforementioned geometry will be presented. In addition, the extension of this analysis to EM scattering from a multilayered anisotropic cylinder, at oblique incidence, will be discussed.

SCATTERING AND ABSORPOTION BY LONG CHAINS OF PARTICLES OF BRANCHED STRUCTURES: M. F. Iskander* and H. Y. Chen, Electrical Engineering Department, University of Utah, Salt Lake City, Utah 84112 and J. E. Penner, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94550.

Calculation of electromagnetic (EM) scattering and absorption of aerosol particles has many applications including characterization of atmospheric aerosols and predicting their climatic impact, evaluation of smoke effectiveness in obscuration, calculation of radiant heat transfer from flames, and in the evaluation of the various scenarios of nuclear winter. The utilization of global transport and scavenging models such as the general circulation model, critically depends on accurate quantification of the amount as well as the scattering and absorption properties of carbon aerosols.

Although many (EM) scattering and absorption calculations by aerosol particles have been done in the past, there remain two important unresolved issues. This includes, 1) Calculating scattering and absorption by highly-elongated particles in the resonance frequency range, and 2) Extending the calculations to coagulated chains of particles of branched structures such as those often encountered in the atmosphere, as well as in the experimental measurements. In this paper we address these two issues and present results illustrating the accuracy of the developed techniques for making these calculations. For oriented chains of coagulated particles, we developed a new version of the Iterative Extended Boundary Condition Method (IEBCM) which made it possible to make calculations for elongated particles with as high aspect ratio of 250 in the resonance frequency range. Specific modifications of the IEBCM include the implementation of a sectioning procedure and the use of a new segmentation method that made it possible to make calculations for very long oriented chains of aerosols.

The scattering of particles of branched structures on the other hand, is calculated using a volume integral equation formulation (VIEF) and the method of moments solution. A surface integral term was included to account for dielectric discontinuities which in our case occurs only on the outside surface of the object. Comparison between the IEBCM results and the VIEF calculations will be presented both in terms of internal field distribution as well as quantities of engineering interest such as scattering, absorption and extinction efficiencies. Results for variety of branched chains geometries will also be presented at various frequencies. The validity of some qualitative (low frequency) observations regarding the relationship between single and coagulated particles scattering will be evaluated with emphasis on their accuracy in the resonance frequency range.

STOCHASTIC IMPEDANCE BOUNDARY CONDITION METHOD

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A formulation is developed to describe the scattering from axisymmetric, coated, perfectly conducting bodies. In this investigation, the coating is assumed to be inhomogeneous where the electrical properties of the coating permit representation through an impedance boundary condition (IBC) and the inhomogeneities are characterized by a random process. For simplicity, the surface impedance η_s is assumed to vary randomly in circumferential (ϕ) direction only. An arbitrary deterministic variation may exist along the generating curve of the body.

The scattering process is described by a surface integral-equation formulation. The formulation is solved by the Galerkin method using harmonic expansion in ϕ. If η_s is characterized by a stationary process, then circumferential modal decoupling occurs, substantially simplifying the analysis. Numerical results are presented for classes of axisymmetric bodies when η_s is described by a stationary gaussian process.

SCATTERING FROM THE INTERIOR OF A CORNER REFLECTOR

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The scattering of a plane e-m wave from the interior of a metallic corner reflector is examined in this paper. The problem has been formulated using the Spectral Domain Technique (S.D.T.) which is an extension of the moment method into the frequency domain.

The formulation of the problem has been carried out for both the TE and the TM modes of the incident wave. For the TM mode we consider that the reflector consists from two non-electrically connected strips,whereas for the TE mode the solution incorporates electrical continuity of the reflector. Furthermore, we examine models for the induced surface current densities, radar cross sections and the scattered electric and magnetic fields.

For the TM mode only there have been some results available and only for the case of a reflector made up by two tilted strips. Also,regarding the backscattering by corner reflectors,there has been some work published lately [1],[2].

REFERENCES:

[1]: T.Griesser and C.A.Balanis,Backscatter analysis of dihedral corner reflectors using P.O. and P.T.D.,IEEE Trans. on Antennas and Prop.,vol.AP-35,number 10,pp.1137-1147,October 1987.

[2]: P.Corona,G.Ferrara,and C.Gennarelli,Backscattering by loaded and unloaded dihedral corners,IEEE Trans. on Antennas and Prop., vol.AP-35,no.10,pp.1148-1153,October 1987.

RADAR CROSS SECTION PREDICTION USING A HYBRID METHOD

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and Research Laboratory of Electronics
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A hybrid method for radar cross section (RCS) calculation of perfect conductors is discussed. The hybrid method utilizes the electric field integral equation formulation and combines the method of moments and the physical theory of diffraction. The method of moments is employed to cast the governing integral equation into the matrix equation for the problem. Then, the matrix equation is solved using the conjugate gradient iterative method with the initial guess solution provided by the physical theory of diffraction (PTD). The numerical results indicate that with 5 % error criterion and the PTD initial guess solution, accurate solution can be obtained with reduced computation time. For the calculation of monostatic radar cross sections, where the induced surface currents have to calculated for each incidence angle, the solution for the previous angle of incidence with the physical optics phase correction provides good guess solution for the next angle of incidence. The hybrid method is used to calculate monostatic RCS and compared with measurement results for flat plate and corner reflector geometries and also for a simple aircraft model. Based on the cases studied, it is found that the hybrid method coverges and the average number of iterations is fairly insensitive to the number of unknowns and the shape of the target. The average number of iterations was below 10 in most cases and, therefore, a significant savings of computation time can be achieved with the hybrid method for objects with large number of unknowns.

RADAR CROSS SECTION OF COMPOSITE DIELECTRIC AND METAL OBJECTS WITH ARBITRARY SHAPE

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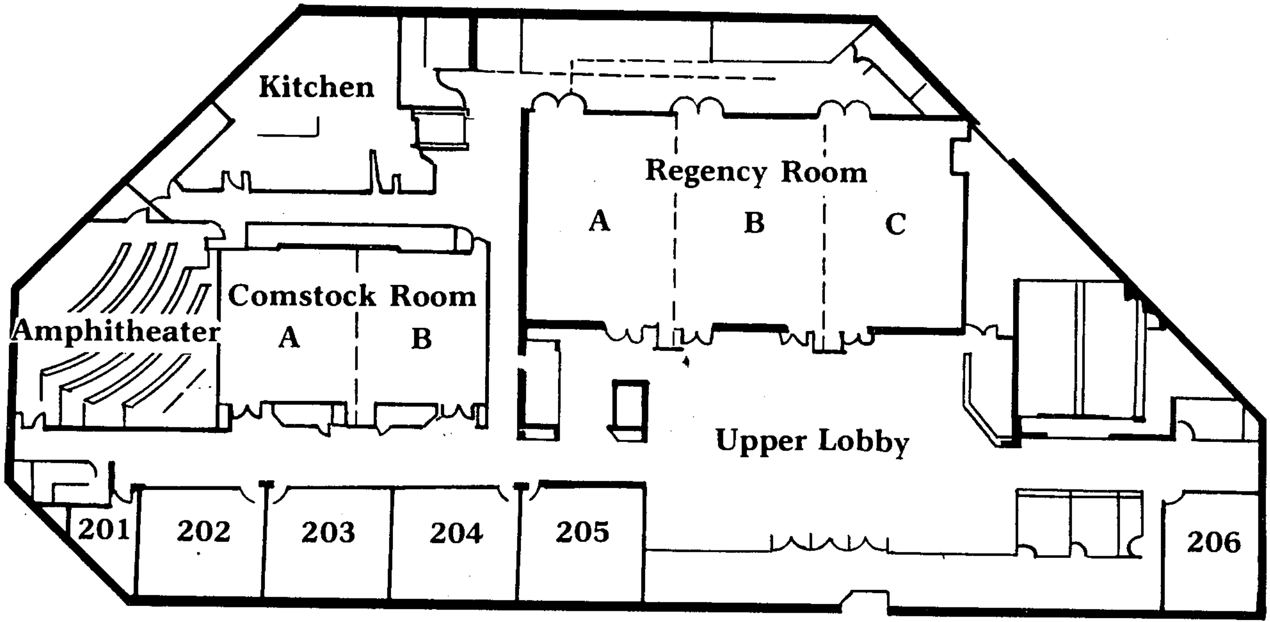
In this paper Integral Equation Formulations and numerical solutions are given for the Radar Cross Section (RCS) prediction of composite dielectric and metal objects with arbitrary shape. Specifically, the RCS of a five-layered lossy dielectric elliptical cylinder is evaluated via the Surface Integral Equation (SIE) formulations and a recursive procedure (Pogorzelski and Wu, 1979 URSI Symp. EM Waves). The RCS of a body-of-revolution model of human is evaluated via the SIE technique (Wu, IEEE Vol. MTT-27, 3, 279-283). Also included is the RCS evaluation of a composite metal and layered lossy dielectric body-of-revolution simulating a missile with a trailing plume. The RCS of a missile/plume is evaluated via the Approximate Integral Equation (AIE) formulations (Wu, et. al., RADC-TR-78-261, 1978).

In general, the major advantages of the integral equation solutions of the scattering from composite objects are 1) arbitrary shape and 2) once the unknown currents are found, the RCS, near and far fields are readily computed. The limitation is that the method is presently only applicable at low frequencies (i.e., resonance region and below). Sample numerical RCS results for the above mentioned composite objects are presented to demonstrate the versatility of the integral equation solutions.

Notes

Notes

AUTHOR INDEX



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1989

IEEE AP-S International Symposium & URSI Radio Science Meeting

June 26 — 30, 1989

Red Lion Inn San Jose, California

Theme: **"New Frontiers in Antenna Applications"**

SYMPOSIUM ANNOUNCEMENT

The 1989 International Symposium and Radio Science Meeting, sponsored jointly by the IEEE Antennas and Propagation Society and by USNC Commissions A, B, E, F, H of the International Union of Radio Science (URSI), will be held at the Red Lion Inn, San Jose, California, June 26 - 30, 1989. The technical sessions for IEEE AP-S and URSI will be coordinated to provide a comprehensive, well-balanced program. Authors are invited to submit papers on all topics of interest to the AP-S and URSI membership. Suggested topics are listed below. Inquiries regarding the technical program may be directed to Professor Kenneth K. Mei, Technical Program Committee Chairman. Information about the Symposium may be obtained from Dr. Ray King, General Chairman, Lawrence Livermore National Laboratory, L-156, Livermore, California 94550, Telephone (415) 423-2369.

SUGGESTED TOPICS FOR AP-S

- *Adaptive antennas*
- *Anisotropic materials in antenna applications*
- *Antenna measurement and metrology*
- *Antenna theory*
- *Biomedical*
- *Environmental effects on waves*
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- *High power antennas*
- *Imaging radars*
- *Impulse radars*
- *Microstrip antennas*
- *Microwave components*
- *Millimeter and submillimeter waves*
- *Near-field measurement and theory*
- *Numerical methods*
- *Phased arrays*
- *Propagation*
- *Reflector antennas*
- *Remote sensing*
- *Scattering and diffraction*
- *Time domain measurements*
- *Very small antenna terminals*
- *Wave propagation theory*

SUGGESTED TOPICS FOR URSI

Commission

A Electromagnetic Metrology
- *Analysis of EM signals*
- *Compact and near-field ranges*
- *Measurements and data signal processing*
- *Satellite/earth station measurements*

B Fields and Waves
- *Asymptotic and iterative solution methods*
- *Microwave holographic diagnostics*
- *Modeling EM coupling through slits, cracks & seams*
- *Near-field scanning technology*
- *Optical control of EM devices*

E Electromagnetic Noise and Interference
- *Noise measurements and modeling*
- *Protection of electronic equipment*
- *Spectrum management and utilization*

F Remote Sensing and Wave Propagation
- *Atmospheric sensing and profiling*
- *Millimeter wave remote sensing*
- *Satellite and aircraft remote sensing*
- *Scattering and emission from the earth*

H Waves in Plasmas
- *Active experiments from space borne platforms*
- *Space borne radar: ionospheric effects affecting performance*
- *Electrodynamic tethers & their interaction with the ionosphere*
- *Latest theoretical and experimental developments in spacecraft charging phenomena*

DEADLINE: ALL SUMMARIES AND ABSTRACTS MUST BE RECEIVED BEFORE JANUARY 3, 1989

Follow the instructions in the call for papers and address all papers to:

Professor Kenneth K. Mei, IEEE AP-S/URSI Symposium
Technical Program Committee Chairman
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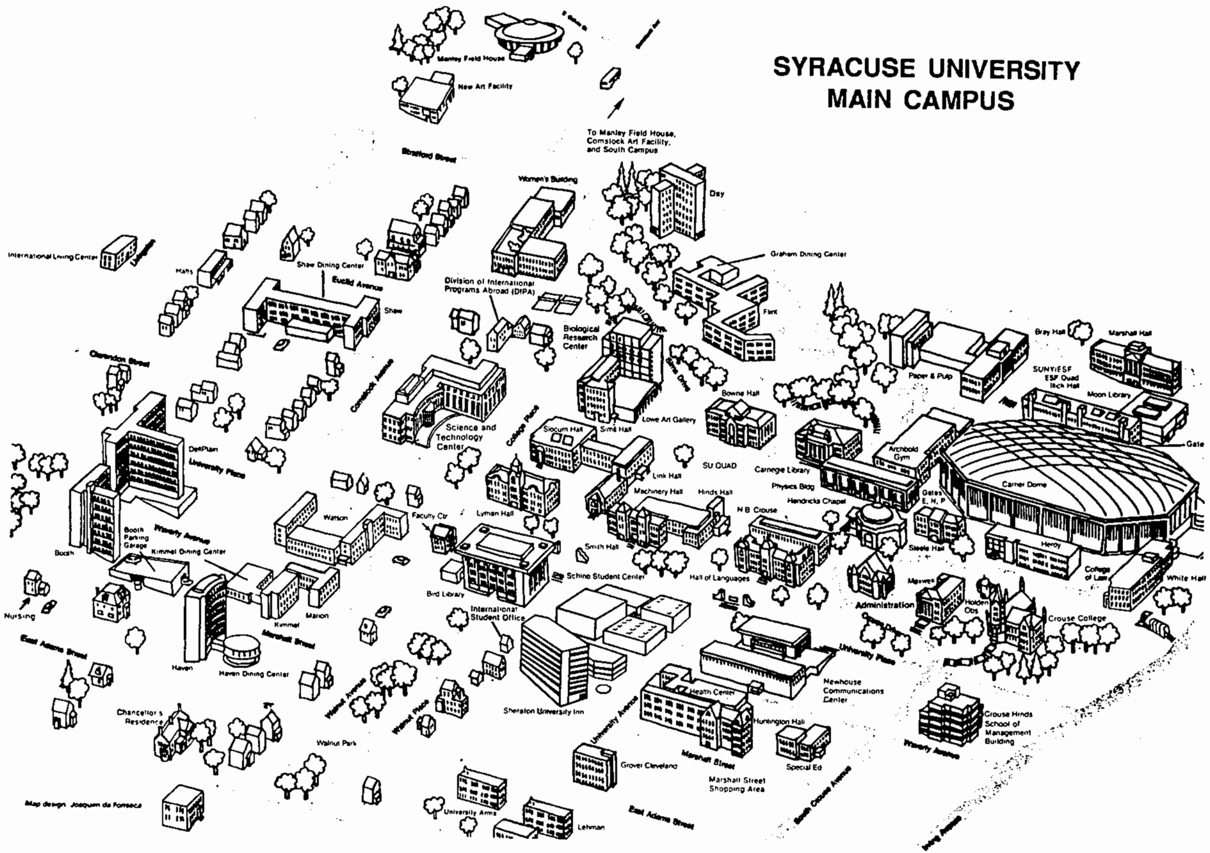

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