1986 NATIONAL RADIO SCIENCE MEETING

International Union of Radio Science

U.R.S.I.

PROGRAM AND ABSTRACTS

June 8-13, 1986

Wyndham Franklin Plaza Hotel
Philadelphia, PA

TECHNICAL PROGRAM SUMMARY

TIME	ROOM	MONDAY, JUNE 9	TUESDAY, JUNE 10	WEDNESDAY, JUNE 11	THURSDAY, JUNE 12	FRIDAY, JUNE 13
8:30 AM-12:00 NOON	WYNDHAM A	AP01 PHASED ARRAYS	AP09 REFLECTOR ANTENNAS I	PLENARY SESSION	AP21 REFLECTOR ANTENNAS III	
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	WYNDHAM C	B-1 ANTENNAS	B-7 NUMERICAL METHODS II		F-4 RADAR METEOROLOGY & OCEANOGRAPHY.	
	WYNDHAM D	AP03 ANTENNA FEEDS I	AP11 DIGITAL BEAMFORMING LOW SIDELOBE ANTENNAS		AP23 AIRCRAFT & SPACECRAFT ANTENNAS	
	PHILA. NORTH	B-2 WAVES IN LAYERED MEDIA	B-8 SCATTERING I		B-16 MICROSTRIP & ANTENNAS	AMTA WORKSHOP
	PHILA. SOUTH	AP04 (URSI A1) MEASUREMENTS	AP12 OPTICALLY CONTROLLED ANTENNAS		AP24 WIDEBAND ANTENNAS	
	SALON 3/4	B-3 RANDOM MEDIA & NON-LINEAR SCATTERING	B-9 INVERSE SCATTERING II		B-17 BEAMS & SCATTERING	AP-S WORKSHOP
	SALON 5/6	E-1 NOISE & INTERFERENCE	F-1 EARTH/SPACE		B-18 EM THEORY II	APS-1 SHORT COURSE
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	WYNDHAM C	B-4 NUMERICAL METHODS I	A-3 EM SCATTERING MEASURMENTS	AP19 ADAPTIVE ANTENNAS	F-5 SENSING EARTH'S SURFACE	
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	PHILA. NORTH	B-5 DIFFRACTION & SCATTERING	B-10 SCATTERING II	B-13 GUIDED WAVES	B-21 SPECIAL SESSION NUMERICAL METHODS	AMTA WORKSHOP (cont.)
	PHILA. SOUTH	AP08 PROPAGATION	AP16 NUMERICAL TECHNIQUES	AP20 APPLICATION OF PC'S	AP27 FREQ. SEL. SURF. & RADOMES	
	SALON 3/4	B-6 INVERSE SCATTERING I	B-11 RESONANCE	B-14 EM THEORY I	B-22 EM THEORY III	AP-S WORKSHOP (cont.)
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	CONFERENCE CENTER BALLROOM	APP1 POSTER SESSION I	APP2 POSTER SESSION II	APP3 POSTER SESSION III		

National Academies of Science and Engineering
National Research Council
of the
United States of America

1986 NATIONAL
RADIO SCIENCE MEETING

PROGRAM AND ABSTRACTS

Sponsored by
The United States National Committee for URSI

Wyndham Franklin Plaza Hotel
Philadelphia, PA
June 8-13, 1986

1986
INTERNATIONAL IEEE/AP-S SYMPOSIUM
& NATIONAL RADIO SCIENCE MEETING
JUNE 9-13

WELCOME TO PHILADELPHIA

I am happy to extend a warm and cordial welcome to you on behalf of the Steering Committee for the 1986 International IEEE Antennas and Propagation Symposium and National Radio Science Meeting. The Steering Committee has planned an outstanding program of Technical Sessions, Exhibits, and Special Events for your edification and enjoyment. I hope you will all find this an exceptionally fine opportunity to update your technical knowledge, renew friendships and thoroughly enjoy the many attractions in and around Philadelphia.

The core of our conference is a fine selection of AP-S and URSI sessions that were organized by the Technical Program Committee. The papers are excellent and cover the many interests of AP-S and URSI members in breadth and in depth. Summaries/abstracts of the papers in these technical sessions are printed in the body of this Digest. As a central part of the Technical Program, an outstanding Plenary Session has been organized with four speakers of renown who will address our major fields of interest on Wednesday morning, June 11.

Exhibits have been added this year as a major new feature. These will be open to all conference attendees on Monday through Thursday. We hope you will take time to visit and support our exhibitors.

We have greatly expanded our workshops this year to include the AMTA Workshop on Compact Ranges, an AP-S Workshop on

Characterization and Packaging of MMIC Devices, and two AP-S Short Courses on Reflector Antennas and on the Method of Moments. These will be held on Friday, June 13.

Philadelphia is known as the City of Brotherly Love, the Cradle of Liberty, and the Birthplace of our Nation. The committee has selected several special events and tours to help you capture this Spirit of Philadelphia. There will be a Wine and Cheese Reception, a dinner-dance cruise down the Delaware River, and an evening of fun in Atlantic City. A highlight of the conference is our annual AP-S Awards Banquet, with fine dining in the Wyndham Ballroom and entertainment provided by one of Philadelphia's own Mummers String Bands.

In addition, special guest tours will be available to take in the sights of the Liberty Bell, Independence Hall, Franklin Court, the Philadelphia Museum of Art, Longwood Gardens, and Winterthur.

Our conference site is the elegant Wyndham Franklin Plaza Hotel. This hotel offers truly superb service and space for our technical sessions, meetings, and exhibits, as well as excellent dining and living accommodations for you and your families.

I would like to thank all the members of the Steering Committee and the Technical Program Committee for their dedication and help in organizing this joint conference. We have all worked hard to bring you an outstanding conference and an opportunity to enjoy the many attractions Philadelphia has to offer. Do enjoy your stay here, and "Get to Know Us!"

Charles C. Allen
General Chairman, Steering Committee

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PLENARY SESSION
Joint with AP-S

Wednesday, June 11, 8:30–12:00 AM

WYNDHAM BALLROOM A&B

Session Organizer: Charles C. Allen
General Electric, Valley Forge, PA

Session Chairman: Kiyo Tomiyasu
General Electric, Valley Forge, PA

Page

ANTENNAS, PROPAGATION, AND RADAR SYSTEMS

MERRILL I. SKOLNIK

Radar Division, Naval Research Laboratory

The technical areas that are included within the scope of the Antennas and Propagation Society are of more than ordinary importance to radar. Radar design and application requires understanding of (1) the antenna as the coupling between the radar and the rest of the world, (2) the propagation of electromagnetic waves in the natural environment, and (3) the nature of scattering from targets and clutter. Of the many diverse radar technical subjects identified with AP-S, scattering has probably received as much attention as any other. Knowledge of scattering from targets and clutter is a key element of target recognition, remote sensing of the environment, detection of targets in clutter, and military applications.

There has been increased use in radar of the planar aperture antenna, low sidelobe antenna, solid-state transmitters commingled with the antenna, phased arrays, and adaptive techniques. To the radar systems engineer "big is beautiful" when it comes to the antenna. There has been less work in radar propagation, other than in the prediction of propagation performance; but there are still unsolved problems in ducted propagation and in predicting low-altitude coverage.

This talk will review several of the areas of antennas, propagation, and scattering that are of concern to the radar systems engineer. It will indicate what is of current interest and what yet needs to be done.

THE RADIO PROPAGATION ENVIRONMENT
FOR
UNIVERSAL DIGITAL PORTABLE COMMUNICATIONS

D. C. COX
BELL COMMUNICATIONS RESEARCH
331 NEWMAN SPRINGS ROAD
RED BANK, NJ 07701-7020

The provision of portable communications, that is, communications to people away from their wireline telephones, is a rapidly expanding communications frontier. The portable communications environment consists largely of rooms, hallways and other space within and around houses and buildings. This environment is characterized by extreme multipath propagation and severe shadowing or blocking of radio paths, both of which result from the presence of walls, ceilings and objects. Quantitative descriptions of propagation parameters such as time delay spread, attenuation, crosspolarization coupling and various signal correlations are needed to facilitate the design of an efficient and reliable Universal Digital Portable Communications System. Only in recent years have measurements of these needed propagation parameters been made. The radio propagation environment for Universal Digital Portable Communications will be illustrated using results from recent propagation measurements made within and around houses and buildings.

EARTH AND PLANETARY OBSERVATIONS WITH SPACEBORNE IMAGING RADARS

Charles Elachi
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, CA 91109

The late 80's and 90's will see a major expansion in the use of spaceborne imaging radars to observe, monitor and study the Earth's surface and to map the hidden surfaces of Venus and Titan.

A series of shuttle imaging radar (SIR) experiments are planned as a joint effort between the U.S. and Germany leading to the development of multispectral multipolarization high resolution imaging systems to be used on the U.S. polar platform (Earth Observing System, EOS) planned for the mid-nineties. The SIR series will build the base for the science, techniques and technology used in radar observation of surface features, properties and phenomena.

A number of free flying orbiting imaging radars are planned by the European Space Agency (1990), Japan (1991) and Canada (1992) with the objective of observing and monitoring long term changes in the ocean features, polar ice and surface cover. These sensors will have imaging resolutions of a few tens of meters.

Similar systems, although less sophisticated, are planned to map the cloud covered surfaces of Venus and Titan. The Magellan spacecraft will orbit Venus in 1988 and carries an imaging radar with the objective of mapping 90% of the planet's surface at a resolution of better than 250 meters. In the late 90's the Cassini spacecraft will orbit Saturn and fly by Titan at least a dozen times. During each flyby an imaging radar will map a strip of the surface at a resolution of a few hundred meters to a few kilometers. By the end of the mission it would be possible to map almost the totality of this mysterious world.

SATELLITE COMMUNICATIONS: PASSAGE TO MIDDLE AGE?

Daniel F. DiFonzo
Communications Satellite Corp.
Clarksburg, Md. 20871

ABSTRACT

The commercial satellite communications industry is barely more than two decades old and is already experiencing symptoms of passage to middle age: The regulated environment of its early youth protected its market share and promoted investment in space and earth facilities designed to maximize transmission capacity for international point to point telephone traffic among a relatively few expensive earth antennas. The rapid growth and vigor of its young adult phase was encouraged by domestic deregulation and adoption of regional satellite systems by many countries. Because of the bandwidth limitations of terrestrial media, satellites proved cost-effective for high capacity requirements, especially TV distribution.

The middle age symptoms of slowing down of growth and awareness of mortality are precipitated by the advent of fiber optics networks and the implications of further deregulation. Now there is much introspection about the competitive position of satellite communications with some arguing that this medium will hardly be used at all for voice traffic and will even suffer in respect to video and data applications unless end to end costs can be reduced. Are satellites then relegated to niche markets such as land mobile, thin route, and point to multipoint? Is this such a bad thing?

This talk will describe these "passages" and the role of advanced network architectures and antenna developments in improving this medium's competitive position to secure its graceful transition to old age.

PHILA. SOUTH
A-1 MEASUREMENTS
Joint with AP-S
Chairman: G. Smith/A. Repjar
MONDAY-AM

A CLOSED FORM SOLUTION FOR ANISOTROPIC MAGNETIC MATERIAL PROPERTIES MEASUREMENT PART I. THEORETICAL FORMULATION

H. H. Chung, G. A. Pfaff and S. Y. Peng
TELEDYNE RYAN ELECTRONICS
8650 Balboa Ave.
San Diego, CA 92123

By using a multiple position cavity method, a closed form solution was obtained for practical application in computing both complex permeability ($\tilde{\mu}$) and complex permittivity ($\tilde{\epsilon}$) of an anisotropic magnetic material. The computation was based on the measured resonant frequency and quality factor (Q) parameters. The pertubation technique and proper boundary conditions were applied in the derivation of the required formulas. An analytical model for a TE011 rectangular waveguide cavity was developed and a set of equations were derived that relate both ($\tilde{\mu}$) and ($\tilde{\epsilon}$) to the change in resonant frequency and unloaded (Q) caused by the insertion of a thin material sample into the cavity. A computer model was generated using the derived equations. A set of final equations and computing procedure has been established for practical applications.

The computer model has been used to identify the properties of unknown Radar Absorption Material (RAM) and known dielectric material. The computed results based on the measured data of resonant frequency and Q parameters for known dielectric material agree well with the published reference data. For the unknown anisotropic magnetic material, the computed results show promising progress made in the development of the RAM. An extensive laboratory investigation was conducted to verify the theoretical model. The detail of the experimental investigation results will be presented in a separate paper. In this paper, the detail derivation will be presented, and application of the formulas obtained will be discussed.

A CLOSED FORM SOLUTION FOR ANISOTROPIC MAGNETIC MATERIAL PROPERTIES MEASUREMENT PART II EXPERIMENTAL INVESTIGATION

G. A. Pfaff, H. H. Chung, and S. Y. Peng
8650 Balboa Ave.
San Diego, CA 92123

To implement the multiple position cavity test method based upon the analytic solution discussed in Part I, an X-band waveguide cavity test fixture was designed and fabricated. A carefully calibrated network analyzer system is used for measuring the complex input impedance of the cavity as a function of frequency. Input impedance was recorded on a specially prepared Smith Chart Data Sheet and frequencies for the resonant frequency and half-power points were carefully measured and recorded.

An extensive laboratory measurement program was conducted to insure data quality. An important consideration in developing the cavity test method was the question of how to accurately position and hold the test samples in the test fixture cavity without introducing a source of error that could not be accounted for. It was decided to use a low density foam material to position and hold the samples in place while making the cavity measurements.

Based upon the samples provided by Aberdeen Proving Ground, a test procedure was developed to measure the resonant frequency and unloaded quality factor (Q) of the cavity for each of the required sample test positions. Three positions are required to determine an anisotropic magnetic material properties. Six positions were selected for this test program. This provided redundant data for cross checking the final test results. A set of known dielectric material was also tested, to provide baseline data for comparison with published values of dielectric constant. The detail test equipment setup, test procedures and the measured results will be presented.

EVALUATION OF ANTENNA MEASUREMENT TECHNIQUES FOR SATELLITE COMMUNICATIONS AND RADAR SYSTEMS

Andrew G. Repjar, Electromagnetic fields Division,
National Bureau of Standards, 325 Broadway
Boulder, Colorado 80303

Near-field techniques, far-field techniques, compact ranges, spherical arch methods, and anechoic chambers are among the options presented when one must choose a measurement system which has the capability to fulfill antenna or radar cross section measurement needs. Each of these methods must be evaluated to determine how well they meet the measurement requirements. Often one measurement system may offer clear advantages in certain areas, but may fall short in another area which is considered critical, and the choice becomes difficult.

To aid in this decision, a three-step evaluation process has been developed which compares the relative merits of the various measurement approaches as they apply to communication satellite, radar, and other antennas. The first step in the process is a clear description of the antenna system to be measured and the identification of the evaluations factors which are determined by the antenna, e.g. size of the test zone, the susceptibility of the antenna to adverse environments, etc. The second step is a description of essential features of the measurement technique under consideration and a definition of the measurement system evaluation factors, e.g. measurement time, practicality to implement, etc. The third step is to assign relative weights to the factors to indicate their relative importance for the particular application being studied. Weighted sums of the evaluation factors are then computed to rate each measurement method.

Using the above process. the details and the assumptions leading to a decision are clearly presented. If there are questions about the final decision, these details and assumptions can be reviewed to verify a correct statement of the problem and justifiable rating of each alternative.

Through this presentation, it is intended that areas of interest and concern, relating to the various measurement techniques be brought to the forefront.

IMPROVED TIME DOMAIN GATING TECHNIQUE FOR ANTENNA MEASUREMENTS

R. Balaberda S.R. Mishra
National Research Council of Canada
Ottawa, Ontario, Canada
KOA OR8

The use of time domain gatings, to reduce multipath reflections errors, has recently become a practical antenna measurement technique because of the recent advances in computing and instrumentation technology. In this technique, measurements are made in the frequency domain, the data is transformed to the time domain, unwanted time components are removed (time gating), and then this gated data is transformed back to the frequency domain. The time gated frequency domain data is then due only to the antenna system free of multipath responses.

A problem with this technique is that the time domain direct and multipath response are stretched out. This stretching (dispersion) is due to the frequency response of the antenna network. Dispersion reduces the shortest path length differences that can be resolved and gated.

The time gating techniques' accuracy can be increased by removing the antenna network's frequency response before gating, and then re-establishing the antenna network's frequency response on the gated data. The frequency response of the antenna network can be either computed or measured.

Details of this dispersion suppressed time gating technique, its applicability to antenna measurements, and some measured data will be presented.

A NEW SCATTERING MATRIX MEASUREMENT TECHNIQUE USING SIX-PORT CONCEPT AND A SLIDING SHORT

L. Kaliouby, R.G. Bosisio

Ecole Polytechnique of Montreal

Montreal, Quebec, Canada

The measurement of reflection coefficient at microwave frequencies has recently been mede possible by using six-port technique, that is, by meens of power readings only, eliminating thus the need for heterodyne technique.

The use of six-port becomes then a very attractive technique for the measurement of the scattering matrix of a symmetrical two-port device. In fact, it is known that to evaluate S_{11}, $S_{12}= S_{21}$ and S_{22}, it's only sufficient to measure Γ when the device under test is successively backed by three different loads, such as a matched load, an open circuit and a short circuit.

However, for a set of measurement that have to be done in real-time or swept frequency mode, the frequent connection and deconnection of loads tond to reduce the repetability and precision of results.

In this paper, a new measurement technique of the scattering matrix, based on the use of a sliding short is developped. It is shown that by plotting the locus of Γ when the position of the sliding short is changed, it's possible by simple graphical means, to deduce most of the relevent information.

WYNDHAM D
A-2—NEARFIELD MEASUREMENT
Joint with AP-S
Chairman: E.S. Gillespie
MONDAY-PM

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2:00	**The Effect of Random Errors in Planar Near-Field Measurements** Allen C. Newell and Carl F. Stubenrauch, National Bureau of Standards	AP Digest
2:20	**Measurement of Array Element Excitations Using a Planar Near-Field Range** K.N. Sherman, Hughes Aircraft Company	AP Digest
2:40	**The Results and Estimates of Uncertainties from Planar Near-Field Measurements on Very Low Sidelobe Antennas** A.C. Newell and M.H. Francis, National Bureau of Standards; K. Grimm and J. Hoffman, Technology Service Corp	14
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THE RESULTS AND ESTIMATES OF UNCERTAINTIES FROM PLANAR NEAR-FIELD MEASUREMENTS ON VERY LOW SIDELOBE ANTENNAS

A.C. Newell, M.H. Francis
Electromagnetic Fields Division
National Bureau of Standards
Boulder, CO 80303

K. Grimm, J. Hoffman
Technology Service Corp.
Washington Division
Silver Spring, MD 20910

An extensive measurement program has recently been completed in which two antennas were tested using the planar near-field technique. From the known design parameters and from previous far-field measurements, both of these antennas were known to have very low sidelobe levels over large angular regions. They were therefore used as test articles to evaluate the accuracy of the near-field technique and to try some new concepts in an attempt to reduce the effect of some sources of error.

Two probes were used in these tests. The first was an open-ended waveguide which has been standard in many near-field measurements. The second was composed of two open-ended waveguides whose outputs were combined in a 180° hybrid. By proper choice of the cable lengths between the two waveguides, a deep null in a direction coincident with the main beam of the test antenna could be produced in the probes receiving pattern. Using the near-field theory, and previous error analyses, one can predict that this type of probe should be less sensitive to some near-field errors. Some of the tests were oriented towards verifying these predictions and determining if the probe had limitations.

In order to quantify the total uncertainty in the measurements for both the OEW and difference probe, a four step process was used. First, known systematic errors from individual sources were introduced in the measurements one at a time, and the results compared with measurements without the introduction of errors. These tests, along with mathematical analysis verified that previously derived error equations were valid for the very low sidelobe antennas and the special probe. Secondly, the magnitude and in some cases the specific character of the error functions were determined for the measurement system. For instance the Z-position error function $\Delta Z(X,Y)$ was determined using laser optical systems. In the third step the error equations and the near-field error magnitudes were combined to predict the effect on the far-field results. In the final step, all of the error sources were combined to give a resultant estimate of error.

The major conclusions were that previously derived error equations and error diagnostic tests are valid for the very low sidelobes antennas; the difference probe does reduce the effect of most systematic and random error sources; multiple reflections between the test antenna and the probe was the largest error source; and total estimated uncertainty for sidelobe levels of -50 to -60 dB was on the order of 5 to 10 dB.

ON THE MODULATED SCATTERING TECHNIQUE FOR RAPID NEAR-FIELD MEASUREMENTS

B. J. Cown
EMED/ECSL/GTRI
Georgia Institute of Technology
Atlanta, Georgia 30332, USA

J. Ch. Bolomey
LSS, Groupe D'Electromagnetisme
Plateau Du Moulon
91190 Gif-Sur-Yvette, France

The modulated scattering technique (MST) [J.H. Richmond, IRE Trans., 1955b, MTT-3, (4)] employs hundreds of electrically-small probes modulated at audio frequencies to rapidly measure the electric field distribution, both amplitude and phase, over a near-field (NF) measurement surface in a few seconds or minutes, depending on whether 2-D or 1-D arrays of modulated scattering elements are employed. Results of recent collaborative research work conducted jointly by the Groupe d'Electromagnetisme (GEM) and by the Electromagnetic Effectiveness Division (EMED) strongly indicate that MST-based NF measurement systems can provide efficient, accurate and cost-effective engineering solutions for a large variety of near-field measurement applications. The MST is particularly attractive for applications involving spacecraft or space-borne antennas, phased array antennas, collection of inverse scattering/microwave imaging data, and for development of portable NF test facilities.

Experimental pattern data obtained via 1st and 2nd generation MST prototype NF measurement systems at GEM and EMED will be compared with classical (mechanically-scanned waveguide probe) NF pattern data for horn antennas and reflector antennas. Factors affecting the speed and accuracy of MST-based NF measurements - dynamic range, interactions of test antennas and MST array, mutual coupling of MST array elements, etc. - will be further discussed and illustrated via results of numerical data simulations. The relative advantages and limitations of the MST will be delineated and discussed with respect to the classical NF technique [J. Ch. Bolomey, Ann. de Telecomm., tome 40, Jan - Feb 1985; B.J. Cown, Final Technical Report, Army contract DAAB07-85-K-KSIS, Feb., 1986] .

COMPUTER SIMULATION OF NEAR-FIELD/FAR-FIELD SCATTERING

William H. Hallidy, William T. Moore and Ivan J. LaHaie
Environmental Research Institute of Michigan
P.O. Box 8618
Ann Arbor, MI 48107-8618

One method of determining the radiation pattern of antennas that has become widely adopted is that of measuring the field on a plane a few wavelengths from the antenna then appropriately weighting the Fourier transform of these measurements to obtain the far field pattern. A theory applying this near-field/far-field transformation method to the scattering problem, where both the transmitter and receiver are in the near-field of the scatterer, has recently been developed (M.A. Dinallo, Proc. AMTA, Oct. 2-4,1984, San Diego, CA) as an extension of the well known plane-wave scattering-matrix (PWSM) theory applied to antennas (D.M.Kerns, NBS Monograph 162, USGPO, Wash., 1981).

A two dimensional computer simulation based on Dinallo's theory has been developed by the authors to study numerical convergence of the transform. Scattering by a cylinder has been modeled for both the TEz and TMz case using eigenfunction expansions for source and receiver positions along a line located a finite distance from the cylinder. A discrete Fourier transform was applied to ascertain the far field radar cross section (RCS), which was subsequently compared with the RCS obtained from the eigenfunction expansion for asymptotically disposed source and receiver locations. The source and receiver are considered to be ideal in this simulation.

In contrast to antennas, which normally do not radiate significant amounts of energy at wide angles to boresight, nearly all targets scatter significantly at large angles to the illumination direction. This wide angle scattering manifests itself as numerical instabilities in the Fourier transform of the sampled field at the highest spatial frequencies. These, in turn, cause a ringing problem in the transformed field that was removed by modifying the measurement window. Resulting plots of the RCS are found to agree to within 0.5 dB for source and receiver lying within a 120 degree sector centered on a line perpendicular to the measurement line.

WYNDHAM C

A-3—EM SCATTERING MEASUREMENTS

Chairman: W.J. English

TUESDAY-PM

AN ANALYSIS OF COMPACT RANGE MEASUREMENTS

P.H. Pathak , R. G. Kouyoumjian
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

A. Nagamune
Nippon Kokan K.K., Technical research Center
Kawasaki-Ku, Kawasaki 210, Japan

Compact range technology has recently received considerable attention and has led to the design of sensitive systems for the indoor measurement of far-zone antenna and scattering patterns.Typically such a compact range contains an offset fed parabolic reflector antenna whose near zone field approximates that of a plane wave over a significant fraction of its projected aperture. The justification of the near field measurment of far zone patterns is based on reciprocity, which leads to the following expression for the open-circuit voltage at the terminal of the measuring antenna,[R. Kouyoumjian and L. Peters Jr., Proc. IEEE, Vol. 53, No. 8 Aug. 1965, pp 920-928].

$$V^r = -\frac{1}{I^i}\int_S \left(\vec{J}_s \cdot \vec{E}^i - \vec{K}_s \cdot \vec{H}^i\right) ds \tag{1}$$

in which the integration S is taken over the surface of the antenna or scatterer being measured; $\vec{E}^i$, $\vec{H}^i$is the incident field due to the constant current I^i connected to the aformentioned terminals (with the scatterer or antenna absent), and$\vec{J}_s$,$\vec{K}_s$ are the equivalent electric and magnetic surface currents of the scatterer (antenna) radiating in the presence of the receiving antenna, support, etc.

In this paper the above expression is used to analytically determine errors in the measurement due to the deviation of the incident field from a uniform plane wave with a prescribed polarization, the coupling between the compact range antenna and scatterer (antenna) and the coupling between the support and scatterer (antenna). The former effect is of primary interest here. Using spherical scatterers and wire scatterers (antennas) as examples, it is shown that even though edge diffraction can be made quite small either via serrating the edge, or by rolling the edge [W.D. Burnside and A.K. Dominek, AMTA Conference,Melbourne, Fla., Oct. 1985], significant errors may occur due to the inherent cross polarization in the field of the feed directly reflected from the surface of the parabola. Methods for reducing these errors are discussed.

HIGH RANGE RESOLUTION TECHNIQUES FOR BROAD BAND COHERENT RADAR

Eric K. Walton
The Ohio State University ElectroScience Lab.
1320 Kinnear Road, Columbus, OH 43212

The process of transforming wide band coherent radar scattering data to the time domain is important in the study of the various mechanisms inherent in scattering from a complex radar target. This paper describes a technique for the time domain transformation which concentrates on the task of finding the time of arrival of a particular signal component to a high precision. This technique works best if the particular scattering modes of interest approximate an impulsive function in the time domain over the bandwidth utilized.

If a radar target is considered to be a collection of scattering centers, each of which is small with respect to a wavelength, it can be seen that the quantities measured as a function of frequency with a coherent radar system (the I and Q components) are made up of a set of sinusoids where the period is related to the distance of the associated scatterer from the phase reference zero plane. A Fourier transform of I(f) or Q(f) will recover the distribution of amplitude versus time (and also distance).

This paper discusses a technique for the high resolution location of such scattering centers. In this technique, a Gaussian window is first applied to the I(f) or Q(f) data, and then a Fourier transform is used to transform to the time/distance domain. The result is that the responses in the time domain are Gaussian (even if the original data were noisy). In the case where the responses are not overlapping, it can be seen that the center of each such Gaussian represents the location of the associated scattering center.

This paper will show that it is possible to achieve much higher resolution than the classical inverse of the observation bandwidth (in this non-overlapping case). This can be done by fitting a Gaussian to the time/distance domain data.

The limitation of the technique will be discussed, examples will be given, and comparisons with SEM/autoregressive techniques will be discussed.

TRANSIENT POLARIZATION SIGNATURES OF ELECTROMAGNETIC SCATTERERS

N. F. Chamberlain, E. K. Walton, F. D. Garber

The Ohio State University
ElectroScience Laboratory
Electrical Engineering Department
Columbus, Ohio

The polarization state of an electromagnetic wave can be represented by two orthogonal vectors, e.g. horizontal and vertical are commonly used. Plotting the instantaneous locus of the electric field vector yields the familiar ellipse (in general), or circles, straight lines etc. Although we refer to this depiction as being 'instantaneous', which indeed it is, the plot usually represents only one frequency.

If backscatter data from a conducting object are available over a band of frequencies, the data can be transformed into the time domain to obtain the band limited impulse response of the object. The result is a time history of the scattering process as a plane wave washes over the object. If we display the received vertical component versus the received horizontal component as a function of time, for the case of circular illumination, we have in effect, a time domain polarization plot.

This paper discusses some recent findings when a variety of perfectly conducting objects are subject to illumination by impulsive plane electromagnetic waves having (synthesized) circular polarization. Our data were measured in the 1-12 Ghz band using the compact range at the ElectroScience Laboratory. The purpose of this study is to gain insight into the manner in which the various physical features of an object influence the polarimetric behavior of its backscatter, and to evaluate the potential of the application of these signatures to identification of the object.

MEASURED IMPULSE RESPONSE POLARIZATION MATRIX FOR OFF-AXIS ANGLES ON A SQUARE PLATE

Jonathan D. Young
Paul Reed
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

The impulse response waveforms were measured for all polarizations and several off-axis look angles on a flat 30cm square plate. The frequency spectrum of the data spans the region $.6 < kL < 100$, where L is the length of the plate edge. The system used was the OSU compact range, with pulsed stepped cw frequency-domain transfer function measurement, vector background subtraction, and calibration with a 15 cm conducting sphere.

The impulse waveforms to be presented show that there are a relatively small number of scattering centers, each with an identifiable time-domain shape and polarization response. The properties of these features vs target geometry will be discussed.

EXPERIMENTAL DETERMINATION OF THE SCATTERING MATRIX FOR RAIN IN THE X- AND Q-BANDS

David W. Carnegie, Amit P. Agrawal and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Engineering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

ABSTRACT

This paper presents an evaluation of an experimental program done to measure the full scattering matrix for rain as a function of the weather conditions under a contract to the Army Missile Command (MI-COM/AMSI-REG-POL, STAS 1597, Contract No. DAAG29-81-D-0100). The data consists of fifty files representing varying weather conditions. Each data file consist of rain cell scattering matrix data given as a discrete time sequence in the X- and Q-bands (8.9 GHz and 45 GHz, respectively). The X-band data consists of 2048 points spaced 400 micro-sec. for a total elapsed time of about 0.8 sec. The Q-Band consists of 32 points spaced 400 micro-sec. so that they span a time of about 13 μsec. The scattering takes place in a "rain cell" defined by the beam widths and down range distances 275 ft. through 325 ft.

Our initial analysis of these data sets concentrated on calculations of autocorrelation and autocovariance functions for the matrix elements. Considerable structure is apparent in the resulting plots, notably a periodic fluctuation imposed on a decaying function. This structure corresponds to an observed periodic fluctuation in the magnitudes of the elements of the scattering matrix. From the plots of the autocorrelation function we may determine the "decorrelation time" for rain as a function of the weather conditions. Additional results from the analysis of the magnitudes and relative phases of the scattering matrix coefficients, co-pol and x-pol null polarizations, differential reflectivity (Z_{DR}), and circular depolarization ratio (CDR) were determined and are interpreted.

Our analyses demonstrate the usefulness of polarization measurements and point out the need for continued experimental work and expansion of this applied polarimetric research.

POLARIMETRIC RADAR SIGNAL OPTIMIZATION IN THE PARTIALLY POLARIZED CASE FOR TARGET DETECTION IN CLUTTER

Alexander B. Kostinski and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Engineering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

ABSTRACT

The procedure for finding optimal polarizations is proposed for the case of partially polarized waves reflected off non-stationary radar targets. It is based on Kennaugh's characteristic target operator theory and our recent "three stage" extension of it.

We assume that complete coherency matrix information (or equivalently, Stokes vector) is available from radar measurements. Based on this information a unique decomposition is performed into a completely polarized and a completely unpolarized part. Only the completely polarized part of the reflected signal is then used to define a target scattering operator. The problem of optimizing the voltage at the receiving antenna terminals then reduces to the completely polarized case optimization, i.e., Kennaugh's optimal polarization theory. We have generalized that theory to a non-reciprocal and bistatic case by employing the three-stage procedure which involves solving an eigenvalue problem for the Graves power matrix and then adjusting the receiver polarization via the voltage match condition. (For a more detailed discussion see a companion AP-S paper.) Various time-scale limits of coherency-matrix decomposition are analyzed in detail.

Such a procedure can also be used for an improved detection of fluctuating and distributed targets.

ASSESSMENT OF POLARIMETRIC MILLIMETER WAVE SENSORS IN THE DESIGN OF AIRBORNE/MARINE GROUND VEHICLE COLLISION AVOIDANCE AND TRAFFIC FLOW CONTROL RADARS

Matthias Walther and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Engineering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

ABSTRACT

Recent advances in integrated circuit technology applied to millimeter wave technology has resulted in the design of small and portable radar devices capable of detecting targets within a closed range (several meters) and up to several kilometers. Of special interest is the FM/CW radar mode of operation, providing very good resolution for small targets under adverse weather conditions (rain, fog, snow, dust) when optical/laser sensors fail in their operation.

Not just the military, but also the civil sector is being introduced to a whole new array of advanced and less expensive radar devices and it is one of the first objectives to critically assess developments of millimeter wave devices already in use in medical radiometry, chemical and industrial measurement/process control, automatic airborne/marine/land vehicle collision avoidance, atmospheric sounding, etc.

A critical review of existing technology in R&D efforts within EC/Japan/Korea/Taiwan and US/Canada is provided. In particular, non-cooperative stand-alone automotive collision avoidance and integrated traffic flow control radars are analyzed and various approaches are critically assessed. In our evaluation we found that, although FM/CW radar systems have been highly advanced, great need exists in improving methods of interference suppression from roadside/atmospheric backscatter. Most recently, several polarimetric millimeter wave radar principles are being considered and investigated, including beam sharpening and polarization diversity switching for backscatter interference reduction and transfers traffic flow monitoring.

WYNDHAM C
B-1—ANTENNAS
Chairman: B.D. Steinberg
MONDAY-AM

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A SIMPLE LEAKY WAVE ANTENNA
THAT PERMITS FLEXIBILITY IN BEAM WIDTH

A. A. Oliner
Polytechnic Institute of New York
Brooklyn, New York, USA

and

P. Lampariello
University of Rome "La Sapienza"
Rome, Italy

Last year we described a new leaky wave antenna based on groove guide that was particularly simple in form ("A New Simple Leaky Wave Antenna for Millimeter Waves," URSI Symposium Digest, p. 57, Vancouver, Canada, June 17-21, 1985). The antenna possessed many merits but it had one disadvantage; it leaked strongly under most conditions, so that it readily yielded wide beams, but narrow beams were achieved only for restricted dimensional ranges. We now present a modification of that structure that permits great flexibility in the range of desired beam widths.

The structure discussed last year consisted of groove guide bisected longitudinally with a metal wall along the long axis of its cross section. The cross section then looks like a length of parallel plate guide with a short tee stub at its center but on one side only. An accurate analysis of the phase and leakage properties was conducted by deriving an equivalent circuit for the tee stub configuration and then employing it in a transverse resonance procedure.

By symmetry, that structure can also be bisected along the narrow axis of groove guide, producing as a result an open waveguide with an L-shaped cross section, where one end (say, the horizontal one) is closed and the other end (the vertical one) is open, permitting the leakage of radiation. The performance characteristics are not affected by this second bisection. In the modified structure, for which results are presented here, the vertical portion of the L, which may be regarded as an open stub, is moved from its end position to some position nearer to the center. In the exact central position, the structure resembles groove guide bisected horizontally, and no radiation is produced. At the other extreme, with this open stub at one end, we have the antenna discussed last year, which leaked very strongly. The leakage rate can therefore be controlled by locating the open stub at intermediate positions.

This modified structure has been analyzed in accurate fashion, and numerical results are presented which illustrate the flexibility in beam widths obtainable because of the new degree of freedom described above.

COUPLING EFFECTS IN AN NRD GUIDE LEAKY WAVE ANTENNA

H. Shigesawa and M. Tsuji
Doshisha University
Kyoto 602, Japan

and

A. A. Oliner
Polytechnic Institute of New York
Brooklyn, New York 11201

Nonradiative dielectric (NRD) guide, a waveguide suitable for millimeter-wave integrated circuits, consists of a dielectric strip placed between parallel metal plates with the electric field oriented parallel to the plates. The basic mode is purely bound, and all discontinuities are purely reactive when the plate separation is less than $\lambda_0/2$.

It was shown (A. A. Oliner, S. T. Peng and K. M. Sheng, "Leakage from a Gap in NRD Guide," IEEE International Microwave Symposium Digest, pp. 619-622, June 1985) that an air gap introduced between the dielectric strip and one of the plates produces asymmetry that converts some of the field to a TEM mode that leaks away at an angle from the region of the strip. When the plates are made finite in width, the structure with an air gap becomes a leaky wave antenna.

The performance of this class of antennas was analyzed by means of a rigorously phrased mode-matching procedure, and the variation of the phase and leakage constants was obtained as a function of the dimensional parameters and the frequency. For small values of leakage, corresponding to radiated beams with beam widths of only a few degrees, the behavior was basically what we expected, with the antenna capable of simple and straightforward design.

For larger leakage values, however, some very odd and unexpected results were found. On closer examination, we noted that the finite width of the plates creates another type of leaky mode that resembles the channel guide mode associated with rectangular waveguide possessing an open side. That new mode can couple with the basic leaky mode over a wide range of parameter values, with the result that the antenna performance is seriously affected. We present not only the coupling effects but some design considerations with regard to how to overcome them or work with them.

FINITE LENGTH HELICAL SHEATH ANTENNA IN A GENERAL HOMOGENEOUS MEDIUM

John P. Casey
Naval Underwater Systems Center, New London, CT 06320
and
Rajeev Bansal
Department of Electrical Engineering and Computer Science
The University of Connecticut, Storrs, CT 06268

The sheath helix is an anisotropically conducting cylindrical tube that represents a good approximation to an actual helix consisting of many turns per wavelength. The problem of an infinite length helical sheath antenna in free space was studied by Chen (Radio Science, 1, 589-600, 1966) to determine the asymptotic behavior of the current and the radiation pattern. In this paper, an integral equation for the current distribution along a finite length, axisymmetrically-driven helical sheath antenna in a general homogeneous medium is derived. This "Pocklington type" integral equation is based on an applied electric field source along the helical direction. The equation is solved by the method of moments to obtain the current distribution and radiation pattern of the antenna. The characteristics of various helical sheath antennas in both dissipative and nondissipative media are presented and compared with multifilar helices.

PHASE CENTRE CONSIDERATIONS FOR THE LOG-SPIRAL ANTENNA

J. M. TRANQUILLA AND S. R. BEST
DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF NEW BRUNSWICK
FREDERICTON, N. B. CANADA

SUMMARY

Many modern electronic distance measurement applications require positioning accuracy of the order of the dimensions of the system antenna. One of the most important such applications is the Global Positioning System (GPS) which uses a network of satellites to provide earth based users with positioning information. One of the significant error sources in this system is the angle-dependent phase centre displacement of the receiving antenna. One of the common antenna types used in GPS is the short logarithmic-spiral antenna which produces the necessary endfire circularly-polarized pattern.

The log-spiral antenna is analysed using the Method of Moments to obtain the radiated field amplitude and phase characteristics. The phase centre, which is defined for a transmitting antenna as the apparent source of radiation, is calculated as a function of polar observation angle by finding the apparent centre of curvature of the radiated equiphase contour. For an antenna of finite extent, the shape of the equiphase contour departs from that of a uniform sphere and the phase centre will become displaced from the antenna as a function of observation angle. The phase centre displacement is calculated based on a formulation by Carrel (1961), that calculates the the phase centre evolute, which is the locus of the phase centre position as a function of observation angle, where the only constraint is that the evolute is symmetrical about the antenna array line.

The suitability of the short log-spiral antenna for GPS applications is discussed and both theoretical and measured antenna characteristics are presented.

C-BAND RIGID HELICAL ANTENNA

A. Kumar
Antenna Engineering
Spar Aerospace Limited
21025 Trans-Canada Highway
Ste-Anne-de-Bellevue
Quebec
Canada H9X 3R2

The helical antenna is of increasing interest in the satellite communication where the limited space is available. It is also important to increase the rigidity of the antenna without using a thick wall dielectric cylinder. The helical antennas have been studied by many authors for various applications.

The purpose of this paper is to describe the design, development and testing of a small ground plane helical antenna for satellite application in the frequency range 5.925 - 6.425 GHz. The matching of the antenna has also been improved using metal strips at the feed point.

The diameter of the helix and the diameter of the ground plane were 0.0160 m. The helical antenna was placed inside a Kynar tube and it was rotated in front of a heating element for a few minutes at 350°C. The Kynar tube shrunk and formed a zig-zag layer on the helical wire and provided a rigid support to the antenna. The thickness and the relative permittivity were 0.0003 m and 2.10, respectively.

It was necessary to improve input matching by increasing the conductor size near the ground plane to reduce the helix impedance from 140 Ω to 50 Ω. Two metal strips were placed on the first turn of the helix. The return loss was then better than -24 dB for both antennas in the frequency range 5.925 to 6.425 GHz. Symmetrical radiation patterns were found of the helical antennas with and without Kynar tubing.

BANDWIDTH OPTIMIZATION FOR SPECIFIED ANTENNA GAIN PATTERNS*

R. M. Bevensee
Lawrence Livermore National Laboratory, Livermore, CA 94550

An expression for the two-sided fractional bandwidth B ($\lesssim$ 100%) of a lossless metal antenna in free space has been derived, in terms of a rigorously defined time-average "reactive stored energy" W_R at center frequency ω_o (R. M. Bevensee, Proc. ISAP '85 Japan, II, 389-392, 1985). This energy is computed as a double integral of the current distribution within the antenna working volume, without employing any spherical wave expansion outside the volume. The currents also determine antenna gain $G(\theta,\phi)$ and time-average radiated power P_{av}, hence the bandwidth $B = P_{av}/(\omega_o W_R)$.

That thin-wire dipole distribution which maximizes both the unidirectional gain G_o and B has already been computed for a spherical working volume of radius $a/\lambda = 2\pi$. In this paper various highly directive patterns $G(\theta,\phi)$ are specified for an antenna working volume of fixed electrical size. For each $G(\theta,\phi)$ and for various dipole distributions to realize it, the dipole currents are found at ω_o to realize G in a mean-square sense. Those currents determine W_R and P_{av} and hence B. By studying B for the various dipole distributions, we will deduce that distribution with the maximum B for each specified $G(\theta,\phi)$.

These results will indicate the class of antennas with inherently high bandwidth for specified gain pattern and electrical size.

* 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.

DESIGN CONSIDERATION FOR SATCOM TERMINAL MMIC ANTENNA ON ADVANCED AIRCRAFTS

C. J. CHEN

TRW, INC., REDONDO BEACH, CALIFORNIA

The design of SATCOM terminal antenna on advanced aircraft requires low prime power in addition to requirements of low radar cross section, small volume, light weight, minimum drag. A conformal active phased array tends to be able to meet most of these requirements. The low prime power requirement impose a new restriction on the size of antenna, as contrary to the conventional passive array. The active array comprised of solid state components: buffer amplifiers, phase shifters, control circuits, and power amplifiers. A formulation relating EIRP requirement for transmit array, gain, size of arrays, prime power, radiation, VSWR, radome loss, insertion loss, amplifier efficiency, solid state biasing loss, will be given. The result shows that using the state of the art solid state components, there is a trade-off between the available prime power and the desirable EIRP. By properly selecting an optimum size of the array, a minimum prime power can be evaluated to satisfy EIRP requirements. The formulation also suggest that to meet the future EIRP and prime power requirement for an active array on advanced aircrafts, a list of design goal for solid state components design and radiation design can be made in accordance with the formulation.

DIELECTRICALLY LOADED WIRE ANTENNAS

John P. Casey
Naval Underwater Systems Center, New London, CT 06320
and
Rajeev Bansal
Department of Electrical Engineering and Computer Science
The University of Connecticut, Storrs, CT 06268

The radiation and circuit characteristics of metallic antennas can be significantly altered by dielectric loading. This dielectric loading may be a human body in the vicinity of the antenna, a dielectric sheath surrounding the antenna to insulate it from the ambient medium, or a dielectric core about which the antenna is wrapped. Previous analyses of dielectrically loaded wire antennas have been restricted as to the geometries of the antenna and/or the dielectric body. Clearly, a need exists for developing a general numerical technique to analyze a curved thin wire antenna in the presence of an arbitrarily shaped finite dielectric body.

In this paper, the problem of a dielectrically loaded curved wire antenna is formulated in terms of two coupled integral equations for the unknown current along the antenna and the induced volume polarization current in the dielectric (Karimullah et al., IEEE Trans., MTT-28, 1218-1225, 1980). The equations are solved by the method of moments to obtain the circuit and radiation characteristics of the antenna. The numerical algorithm is applied to the analysis of dielectrically loaded loop and helical antennas. The computed results are compared with previous experimental and theoretical data.

PHILA. NORTH
B-2—WAVES IN LAYERED MEDIA
Chairman: D.A. Hill
MONDAY-AM

ANALYSIS OF AN ARRAY OF TM-EXCITED STRIPS RESIDING ON A PLANAR INTERFACE BETWEEN TWO SEMI-INFINITE HALF SPACES

Chalmers M. Butler and Xiao-Bang Xu
Department of Electrical and Computer Engineering
Clemson University
Clemson, SC 29634-0915

In this paper is presented an analysis of scattering from an array of TM-excited conducting strips resting on a planar interface separating two semi-infinite half spaces. The strips are of infinite extent with their axes parallel to the media interface. Coupled integral equations for the currents induced on the surface of the strips are formulated and numerical methods for solving the integral equations are developed. In general, the kernels of the coupled integral equations are two-dimensional Sommerfeld-type integrals, but, in the special (but important) case that the permeabilities of the two half-spaces are the same, it can be shown that these integrals can be represented in closed form (C.M. Butler, "Current induced on a strip which resides on the planar interface between two semi-infinite half-spaces, IEEE Trans. Ant. and Propagat., pp. 226-231, vol. AP-32, no. 3, March 1984). In this situation the integral equations can be solved very efficiently and the induced current determined without excessive computer costs. In addition, the far-zone scattered field is computed by an asymptotic approximation technique. The induced currents and the far-zone scattered field patterns are presented graphically as functions of the various parameters of the problem.

COUPLING BETWEEN A PAIR OF ANTENNAS SEPARATED BY A PLANAR INTERFACE

David A. Hill
Electromagnetic Fields Division
National Bureau of Standards
Boulder, CO 80303

There are numerous practical cases (such as mine communications) where antennas are located in different media separated by a planar interface. In this paper we use the plane-wave spectrum technique to describe the coupling between an arbitrary pair of antennas in terms of their plane-wave transmitting, receiving, and scattering characteristics. The approach is a generalization of Kerns' plane-wave scattering matrix formulation for coupling between a pair of antennas located in a homogeneous medium [D.M. Kerns, Plane-Wave Scattering-Matrix Theory of Antennas and Antenna-Antenna Interactions, National Bureau of Standards Monograph 162, Washington: U.S. Government Printing Office, 1981]. The extension of Kerns' formulation to a half-space geometry is fairly direct because each plane wave component of the total field is reflected and refracted at the interface without mode conversion. Multiple reflections between the antennas and the interface are included in the theory, and there is no restriction on the distances between the antennas and the interface.

The formulation can also be used to model the detection of subsurface targets if we replace one of the antennas by a passive scatterer. In this case the transmitting antenna is located in air, and the passive scatterer is located in a lossy earth [G. Kristensson and S. Strom, Radio Sci., 17, 903-912, 1982]. Plane wave excitation [H.S. Chang and K.K. Mei, IEEE Trans. Geosci. Rem. Sens., GE-23, 596-605] is also included as a special case. To illustrate the general theory, we consider the case of a loop antenna in air and a buried oblate spheroid.

Fields Due to a Dipole Antenna Mounted on Top of a Conducting Pad of Finite Extent in a Layered Stratified Medium

D. Gaylor[*], T.M. Habashy[+], and J.A. Kong[*]

[*] Department of Electrical Engineering and Computer Science,
Massachusetts Institute of Technology
Camb., MA 02139
[+] Schlumberger-Doll Research
Old Quarry Rd
Ridgefield, CT 06877-4108

In this paper, we analyse the fields resulting from a dipole on top of a perfectly electrical conductor of a finite extent in a planar stratified medium with the axis of stratification perpendicular to the conductor. This problem serves as a canonical problem that helps in modelling some of the tools used in geophysical applications. It is more pertinent to tools operating at high frequencies and that are mounted on a pad.

The problem is formulated using the method of moments, where the electric fields in the open space is represented in terms of a continuous spectrum of modes that takes the effect of startification into consideration, whereas the current on the conductor is represented in terms of a complete set of basis function that takes into account the edge condition. The boundary conditions are then applied to the electric field components tangential to the pad and to the current flowing on the pad. This allows us to solve for the currents on the pad and hence the fields everywhere.

FAR FIELDS OF AN INCLINED MAGNETIC DIPOLE OVER A LOSSY GROUND

R. Nevels and J. Izquierdo
Department of Electrical Engineering
Texas A&M University
College Station, Texas

In most cases authors have investigated loops that are small in terms of wavelength. This is a useful assumption since the loop can be approximated by a magnetic dipole. This approximation is not over restrictive as long as the far fields are all that need be found.

The small circular loop over a ground has been studied for a variety of reasons. It has been suggested that the small loop could be used in remote sensing applications to determine the properties of the earth and to locate trapped miners. Researchers have also investigated the potential of communications between transmitter and receiver where one or both are submerged in water. In each of these cases the ability of the loop to focus energy into the second region is considered important.

For the purpose of focusing the radiated field and because in practical applications the plane of the loop may not be held in a position parallel to the interface we investigate the far fields of an inclined magnetic dipole. Analysis is done by a combined analytical-numerical technique and results are presented for the far space wave field both above and below the surface of a semi-infinite region as a function of angle of inclination.

SOLUTIONS FOR HERTZIAN DIPOLES IN UNBOUNDED UNIAXIALLY ANISOTROPIC MEDIA IN CYLINDRICAL COORDINATES

Young S. Kwon and Johnson J. H. Wang
Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

There has been a growing interest in the solution of electromagnetic problems involving uniaxially anisotropic media. A key element in the solution of this type of problem is the Hertzian dipole radiation in an unbounded uniaxially anisotropic medium, which is equivalent to the dyadic Green's function solution. A representation in the Cartesian coordinates was derived by Clemmow (Proc. IEE, Vol. 110, No. 1, 1963). However, for a variety of problems involving cylindrical boundaries, stratified media, etc., numerical solutions dictate the use of expressions in the cylindrical coordinates, for which no simple, explicit formula is known to exist.

In this paper, we present an explicit closed form expression for a Hertzian dipole in unbounded media which are characterized by uniaxially anisotropic permittivity and permeability tensors, by a scaling technique similar to that of Clemmow. In pursuing solutions in the cylindrical coordinates, we first assume a solution for the anisotropic case related to the known free space case by simple scaling constants for all the physical parameters involved. We then show that this is indeed a solution for Maxwell's equations if appropriate scaling constants are chosen. Since the resulting solutions are of mathematical forms, identical to those for the isotropic case, one can take advantage of the similarities to deal with a variety of problems with techniques well developed for the isotropic case. For the spherical coordinates, it was shown that no simple solution based on this scaling principle exists.

COMPUTATION OF ELECTROMAGNETIC FIELDS DUE TO HERTZIAN DIPOLE IN STRATIFIED UNIAXIALLY ANISOTROPIC MEDIA

Young S. Kwon and Johnson J. H. Wang
Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

Electromagnetic problems involving stratified uniaxially anisotropic media have become increasingly a subject of intensive research. In the present analysis, solutions to the problem are facilitated by treating a general wave field as a superposition of TE and TM fields and by writing the general solution inside a stratified medium and matching the boundary conditions at the interfaces.

General formulas have been developed for the fields in stratified media which are characterized by uniaxially anisotropic permittivity and permeability tensors. The superposition of "primary" and "secondary" fields and the matching of boundary conditions leads to the solution of the problem, which is then computed by the Fast Fourier Transform (FFT) technique used in the isotropic case (J. J. H. Wang, Proc. IEE, Vol. 131, pt. H, No. 1, 58-62, 1985).

A computer program has been written for the case of a vertical electric dipole in a uniaxially anisotropic substrate backed by a ground plane. Since there seems to be no numerical or experimental data available to check against the present computation, we resort to indirect checks and validation. Excellent agreement with the exact image theory was observed. We also observed the strong effects of dielectric anisotropy on the radiated fields in our computed results, which should be of practical importance in a variety of devices and systems. Good agreements were also reached when the algorithm was used to compute the isotropic case for which the results were known. In addition, the numerical data for the anisotropic cases exhibit a good behavior consistent with our expectation.

ACTIVE ARRAY PATTERNS FOR DIELECTRIC COVERED ARRAYS OF APERTURES ON CONDUCTING SPHERICAL SURFACES

by

Dr. Probir.K.Bondyopadhyay
Department of Electrical Engineering
and Computer Science
New York Institute of Technology
Old Westbury, New York 11568.

In an ongoing investigation, the active array patterns for rotationally symmetric arrays of apertures on conducting spherical surfaces with several layers of dielectric cover have been computed. This work relates to the performance analysis of hemispherical feed through dome lens phased array antennas with radome cover.

Results for three rings of circular waveguide fed apertures in the equatorial region will be presented. A sector of the spherical array is illuminated with an amplitude and phase distribution cooresponding to a far zone broadside plane wave front. Two polarizations, one parallel to the equator and the other perpendicular to it are considered.

Computational results show that the dielectric constant and the cover thickness has very strong effects on the active radiation pattern. Effects of creeping waves in this model of analysis is of prime concern.

WAVE PROPAGATION IN MULTI-LAYERED CYLINDRICAL CONCENTRIC MEDIA

Antonio José Martins Soares and Attílio José Giarola
Department of Electrical Engineering
State University of Campinas (UNICAMP)
Caixa Postal 1170
13.100 Campinas, SP, Brazil

I. INTRODUCTION

The analysis of the electromagnetic wave propagation in cylindrical concentric layered media is of interest in optical fibers application, dielectric rod antennas, cylindrical waveguides, coaxial lines, etc. Yet, to the author's knowledge there has been no general formulation for solving the problem of the electromagnetic wave propagation in dielectric media with N cylindrical concentric layers using an eigenfunction expansion [1].

In this paper a compact and general analysis is obtained by using the eigenfunction expansion of the dyadic Green's functions. The scattered dyadic Green's functions are used in their general form along with coefficients to be determined from the boundary conditions. In particular, only dyadic Green's function of third kind of the electric type will be considered. This will allow the calculation of the electromagnetic field for a given electric current density distribution by means of an integration over the volume where this distribution is located. Similar analysis may be accomplished using only dyadic Green's function of third kind and of the magnetic type for cases when the source is a magnetic current density distribution. In the analysis a time dependence of the type exp(-iωt) is assumed, where ω is the angular frequency.

SALONS 3/4
B-3—RANDOM MEDIA AND NON-LINEAR SCATTERING
Chairman: J.A. Kong
MONDAY-AM

THE RELATIONSHIP BETWEEN THE DYADIC FIELD CORRELATION FUNCTION AND VECTOR TRANSPORT THEORY

A. M. Ghuniem and R. H. Lang
Department of Electrical Engineering and Computer Science
The George Washington University
Washington, D.C. 20052

A new relationship between the dyadic two point correlation function of the electric field and the solution to the vector transport equation is derived. The work represents a natural generalization of a scalar relationship previously presented. The result is obtained for an arbitrary volume of non-spherical dielectric scatterers that are sparsely distributed. It is assumed that the background medium is constant everywhere.

A matrix-dyadic formulation of Maxwell's equations is the starting point for the calculation. An approximate equation for the dyadic correlation function of the field is derived by employing the Foldy-Lax closure assumption. By scaling this equation, with respect to scatterer size, the fractional volume is introduced as a small parameter; a two variable perturbation technique is then employed. By using this methodolgy, the dyadic correlation function is expressed as an angular transform of a dyadic two-point specific intensity function. The correlation function satisfies a generalized two point transport equation.

The result is then simplified by showing that the two point dyadic specific intensity function can be related directly to the Stokes parameters; thus a relationship between the field correlation function and the Stokes parameters is obtained. The result, although similar to the usually assumed relationship, has certain important differences. The validity of the new expression has been checked by comparing it with the distorted Born result, when the albedo of the scatterers is small.

Modified Radiative Transfer Theory for a Two-Layer Anisotropic Random Medium

Jay K. Lee
Department of Electrical and Computer Engineering
Syracuse University, Syracuse, NY 13210, U.S.A.
(Tel) 315-423-4395

and

Jin A. Kong
Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.
(Tel) 617-253-5625

The study of electromagnetic field intensity propagation in continuous random medium has been of great interest in the areas of microwave remote sensing of earth terrain media and optical communications in the atmosphere. Although the phenomenological radiative transfer theory handles the multiple scattering effect easily, it loses the phase information of the propagating field, resulting in lack of spatial coherence effect between waves propagating in different directions. On the other hand, the wave theory with the regular perturbation method such as the Born approximation includes the coherent effect, but it does not take into account the multiple scattering effect.

It is the purpose of this paper to include both multiple scattering and spatial coherence effects in solving the problem of the field intensity propagation in an anisotropic random medium layer. The modified radiative transfer (MRT) equations which describe propagation and scattering of the electromagnetic field intensity in a layered anisotropic random medium are derived from the Bethe-Salpeter equation with the ladder approximation and the Dyson equation with the nonlinear approximation. The Dyson equation and the Bethe-Salpeter equation are the exact integrodifferential equations that the first and second moments of the field propagating in a continuous random medium must satisfy, respectively.

Backscattering enhancement is observed due to the spatial coherence effects between upward and downward propagating waves. It also occurs for the half-space case, because of coupling between ordinary and extraordinary waves in an anisotropic random medium layer. The depolarization effect is predicted in the first-order renormalization approximation to the MRT equations.

HARMONIC AND TRANSIENT SCATTERING FROM WEAKLY NONLINEAR OBJECTS

Dan Censor*

Department of Electrical and Computer Engineering and Biomedical Engineering and Science Institute, Drexel University, Philadelphia, PA 19104

ABSTRACT

A mathematical model for scattering of electromagnetic waves from weakly nonlinear objects is developed. The constitutive relations are based on Volterra series, but additional, physically plausible, heuristic assumptions have to be introduced in order to solve the scattering problem. The general theory is discussed in connection with scattering from circular cylinders and spheres, with emphasis on the cylindrical problems. These canonical problems demonstrate the new phenomena involved. It is shown that the first order effects of the nonlinear scattering problem involve modification of the linear scattering coefficients and production of new multipole terms at the fundamental frequency. In addition, part of the energy is transformed into harmonics. The corresponding problem of transient scattering is considered. The new effects of pole migration and pole creation are discussed.

The present study contributes to understanding the theoretical aspects of nonlinear scattering, and may also provide a method for remote sensing of nonlinear targets.

* Visiting Professor, Bessie and Louis Stein Foundation Fellow, on leave from the Department of Electrical and Computer Engineering, Ben Gurion University of the Negev, Beer Sheva, Israel.

AVERAGE FIELD AND INTENSITY IN PARTICULATE MEDIA

David A.de Wolf and Syeda R. Begum
Department of Electrical Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

Abstract

Integral equations for the coherent field and for the mean intensity in a collection of small point scatterers are formulated. They differ from preceding developments in that to good approximation all higher-order correlations between particles are included. The equations are developed from the self-consistent equations for multiple scattering from point scatterers in the "Twersky approximation," which ignores scatterings from particle 1 to particle 2 and then back to particle 1 everywhere. The four lowest-order terms in the binary-correlation expansions correspond to those obtained from Tsolakis, Besieris, and Kohler [Radio Sci. 20, 1037-1052; 1985]. Analysis of the region of validity reveals that the equations are extensions of previous work for large wavelength, i.e. for small particles, and higher densities.

THEORETICAL MODELING OF POLARIMETRIC RADAR CLUTTER

M. Borgeaud, R. T. Shin, and J. A. Kong
Department of Electrical Engineering and Computer Science
and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Mass. 02139

In the study of discrimination and classification of earth terrain utilizing the polarimetric scattering properties, we use a layered random medium model to characterize earth terrain media such as vegetation, forest, snow and ice which exhibit strong volume scattering effects. The random medium has a background permittivity and its randomness is characterized by a three-dimensional correlation function with variance and correlation lengths. The polarimetric properties of the backscattering coefficients can be studied by calculating the full Mueller matrices.

Both radiative transfer theory and wave theory are applied to calculate the radar backscattering coefficients. In the radiative transfer theory, all four Stokes parameters are used to calculate the backscattering cross sections with a numerical approach which provides a valid solution for both small and large albedos. The results obtained with the radiative transfer theory is compared with the results obtained with the wave approach carried to second order in the Born approximation. The first-order solution with the wave approach does not exhibit depolarization in the backscattering direction. Carrying out the Born approximation to the second order gives the backscattering coefficients that account for depolarization effects.

It is shown that the Mueller matrix for a layered isotropic random medium calculated with both the radiative transfer theory and the wave theory has eight of its elements equal to zero in the backscattering direction, which is consistent with experimental results. The Mueller matrix can be transformed to a covariance matrix which is also useful in characterizing the polarimetric scattering properties. The covariance matrix for a layered random medium is shown to have four of its elements equal to zero. The comparison of theoretically calculated covariance matrices with experimental data collected from various terrain will be made and physical interpretations will be given for the properties of the covariance matrix elements.

MICROWAVE PROPAGATION MEASUREMENTS THROUGH A DENSE DISTRIBUTION OF SPHERICAL PARTICLES

Charles Mandt, Yasuo Kuga, Akira Ishimaru
Department of Electrical Engineering
University of Washington
Seattle, Washington 98195

In recent years there has been an increasing interest in microwave scattering and propagation through a dense distribution of scatterers. One example is microwave remote sensing of ground snow which has a fractional volume of more than 20%. The experimental data obtained in situ, however, are difficult to compare with theory because the exact characteristics of the medium are difficult to measure.

In this paper we present experimental results of coherent microwave propagation through a random medium in which the characteristics of the medium such as the particle distribution and the index of refraction are known. The experimental setup consists of a HP 8510 network analyzer which can make accurate phase and amplitude measurements and two horn antennas separated by 470 cm in an anechoic chamber. The scattering medium which is placed 70 cm from the transmitting antenna consists of 10 to 50 layers (depending on the density of the scatterers) of styrofoam with spherical glass beads embedded at predetermined positions generated at random by computer. The beads have an average diameter of 5.7 mm and an index of refraction $n = 2.3 + i0.02$ at 20 GHz. This corresponds to a size parameter ka of approximately 1.1 where k is the wave number and a is the average diameter of particles. The attenuation and phase constants for fractional volume densities of 0.1%, 1%, and 5% are measured in the frequency range of 18 to 20.4 GHz, and the results are compared with Foldy's formula. At high densities, the attenuation constant appears to be less than that of Foldy's formula and the phase shift appears to be greater than that of Foldy's formula.

SCATTERING FROM A FOLIAGE COVERED ROUGH SURFACE

Gary S. Brown, Department of Electrical Engineering,
Virginia Polytechnic Institute and State University,
Blacksburg, VA 24061

The scattering of elecromagnetic waves from natural surfaces has received renewed interest because of a desire to remotely sense both the foliage and rough surface properties. Of course, this can be done quite easily by using very high frequencies and very low frequencies, respectively. However, such frequency diversity is seldom available in unified airborne systems and, in fact, it is highly desireable to use closely spaced frequencies alone with some other characteristic of the scattered signal to isolate the two dominant contributors.

A necessary preliminary to any system design is a good theoretical model for the contribution of both the rough surface and the foliage coverage. The descriptor good in this case is intended to imply a model which is based on sound physical and mathematical arguments and exhibits a resonable degree of correspondence with experimental data. Since this is not a new problem, there are a number of possible approaches which have been attempted previously. Generally, these wisely make use of some simplifying approximation relatively early in their development and so they are inherently limited. The approach developed in this paper is to split the field initially propagating through the foliage into coherent and incoherent parts and then to track the coherent and incoherent scattering effects of the rough surface on these statistical components. As these components are scattered away from the rough surface they are further altered in a coherent and incoherent manner by the foliage. By keeping track of the various types of interactions it is possible to ignore many of them and to select those which dominate in the backscatter and/or forward scatter directions. The analysis is, however, limited to a single downward and upward passage of the incident field through the foliage. The limitations of this approximation are discussed although there are clearly frequency ranges where this is not a serious drawback.

OPTIMAL PROPAGATION OF HIGH-INTENSITY BEAMS IN THE PRESENCE OF RANDOMNESS

I. M. Besieris and M. E. Sockell
Department of Electrical Engineering
Virginia Polytechnic Institute and State University
Blacsburg, Virginia 24061

A significant theoretical contribution made recently by Karobkin and Sazonov [Sov. Phys. JETP 54, 636 (1981)] indicates that a regime of propagation without self-focusing is possible for an optical beam exceeding a critical power, provided that the beam has certain angular characteristics at the input aperture plane. Specifically, the phase front of the beam should be so modulated that the initial angular divergence of the beam as a whole significantly exceeds the diffraction divergence over the entire aperture of the beam; in addition, there should be a certain dependence of the angular spectrum of the wave vectors over the transverse cross section of the beam. Under these "optimal" conditions, the distance over which an intense beam can propagate without appreciable change in its parameters (two-dimensional soliton) is significantly increased.

Our specific intent in this exposition is to examine the effectiveness of the optimal conditions specified by Karobkin and Sazonov in the presence of randomness at the input plane and/or in the channel.

THE EFFECT OF HEIGHT DISTRIBUTION AND CORRELATION ON ROUGH SURFACE SCATTERING IN DIFFERENT PARAMETER REGIMES

Robert J. Papa
John F. Lennon
Richard L. Taylor
Electromagnetic Sciences Division
Rome Air Development Center
Hanscom AFB, MA 01731

In the context of a physical optics model, the dependence of scattering on surface roughness is well known for a surface described by a Gaussian height distribution and Gaussian correlation function. For a smooth surface the scattering is concentrated in the specular direction; then, as the surface roughness is increased, the pattern spreads over an increasingly wide range of elevation angles. For some conditions, though, other statistical forms may be appropriate. For instance, power spectra considerations have suggested alternate correlation functions for sea states. Also, points several correlation lengths apart can be considered statistically independent for a Gaussian height distribution. When heights at widely separated points are still related, the surface might be represented by a bivariate exponential form.

The first topic of this paper is an examination of the scattering from rough Gaussian surfaces with three different correlation functions. The second is the consideration of a surface with a bivariate exponential height distribution for the same correlation functions. The third is extension of these comparisons to the case of heights small compared to a wavelength (perturbation regime).

The results represent comparisons for the two surfaces and three correlation functions for three levels of roughness and a range of incidence angles. For the Gaussian surface the trend of pattern broadening with roughness applies to all correlations, with a Bessel function form showing more variation. For the exponential surface, the statistical dependence at large separations introduces an additional scattering component in the specular direction. For all cases, though, this turns out to be less than the general diffuse component and there is little difference between trends for either surface type. Finally, in the perturbation regime, the pattern does not change significantly with roughness, the height statistics do not appear in the formulation, and there is no concentration of scattering near the specular direction. The use of the Bessel function correlation again introduces some variation. The main conclusion is that the trends differ for the two scattering regimes but, for either case, the only factor that results in any degree of variability is the Bessel function correlation, and those differences are minor.

THE USE OF A NARROW PLATE AS A STIRRER IN A MODE-STIRRED CHAMBER

Doris I. Wu and David C. Chang
Electromagnetics Laboratory
Department of Electrical and Computer Engineering
Campus Box 425
University of Colorado
Boulder, Colorado 80309

It has been shown experimentally that a mode-stirred chamber, when stirred properly, can provide a uniformly random field environment suitable for repeatable measurement data in EMI testing. Specifically, the statistical distribution of the fields in a confined region of the chamber does not vary much from one location to the next. Most of the mode-stirred chambers currently in use have either multiple scatterers, or a less-than-simple stirrer structure. In this paper, we begin with a simple narrow rectangular plate as the stirrer and examine the statistical distribution of the resultant fields perturbed by the rotating plate.

The fields inside a rectangular cavity can be expanded using orthogonal modal functions. Given an incident mode, the scattered field can be found in terms of the unknown induced current on the plate. This equation in turn can be reformulated into a double variational form by invoking the boundary condition on the plate. By assuming a sinusoidal current distribution on the plate with the proper edge conditions taken into account, the scattered fields are calculated numerically using this variational formulation. As the stirrer rotates, data are taken on the fluctuation of the fields at a given location. The effectiveness of this narrow plate acting as a stirrer can be determined by comparing the statistical distributions of the fluctuating fields at different locations. To insure the validity of the assumed current distribution, we also compute the actual current distribution on the plate by formulating and solving the electric-field integral equation using moment methods.

In this analysis, we remove the complications involving the excitation antenna by assuming an arbitrary incident field. Since the analysis will not be complete until we include the excitation antenna, the issues concerning the excitation antenna such as input impedance and power will also be addressed.

WYNDHAM C

B-4—NUMERICAL METHODS I

Chairman: E.F. Kuester

MONDAY-PM

THE APPLICATION OF AN ITERATIVE TECHNIQUE TO SCATTERING BY PERFECTLY CONDUCTING BODIES OF REVOLUTION

G. H. Fallouh, P. K. Murthy and G. A. Thiele
Graduate Engineering and Research
University of Dayton
Dayton, Ohio 45469

The scattering of electromagnetic waves from bodies of revolution with the illumination being along the axis of symmetry is studied. The iteration technique described by [M. Kay, P. K. Murthy and G. A. Thiele, "An Iteration Method for Solving Scattering Problems," IEEE Trans. Antennas and Propagation, Vol. AP-33, No. 11, Nov. 1985] is applied to solve the Magnetic Field Integral Equation (MFIE) for surface current density.

In this method, an arbitrary body of revolution is divided into two regions; lit- and shadow-regions separated by the geometric optics boundary. The total current is the sum of an approximate optics current and a non-uniform correction current. Both of these currents are computed for the lit- and shadow-regions by iteration. Reduced computer time (i.e., rapid convergence) is achieved by selecting the initial guess of the optics currents as being approximately $(2\hat{n} \times \overline{H})$ on both the illuminated and shadowed surfaces.

In this work, the formulation of the problem is illustrated for prolate spheroidal-like geometries to represent the bodies of revolution. The rotational symmetry permits the currents on the surface, in a direction orthogonal to the axis of symmetry (azimuthal direction) to be expanded in a Fourier Series. This will uncouple the MFIE and reduce the problem to a one-dimensional equation. Results will be presented for monostatic and bistatic scattering from bodies of revolution. Finally, some of these results will be compared to other independently derived results.

COMPARATIVE RATES OF CONVERGENCE OF THE CONJUGATE GRADIENT AND OTHER ITERATIVE ALGORITHMS WHEN APPLIED TO A CLASS OF ELECTROMAGNETIC PROBLEMS

A. F. Peterson and R. Mittra
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

Recent interest in the iterative solution of electromagnetic scattering problems has led to the publication of many papers on the available iterative algorithms. These have addressed theoretical properties of the algorithms in detail. In this presentation, we address the actual performance of several iterative algorithms when applied to a variety of typical electromagnetic scattering problems.

For instance, the performance of the conjugate gradient method is consistent and somewhat predictable when used to treat scattering from conducting strips, plates, infinite and finite cylinders, dielectric bodies, and bodies containing both dielectric and conducting material, based on a study of matrix equations obtained from a moment-method discretization using subsectional basis and testing functions. For most of the specific examples under consideration, the conjugate gradient method appears to behave as an iterative method, as opposed to a finite-step method, in that the residuals are reduced at a steady rate throughout the process. Furthermore, solutions to these systems are typically obtained in N/4 to N/2 iterations, where N is the order of the system. The rate of convergence is found to depend on the cell density used within the discretization, and to a lesser extent on symmetries in the solution. Because convergence is seldom extremely fast, the conjugate gradient method can be expensive for large-order systems.

Preconditioning can be applied to speed the convergence of iterative algorithms. This involves transforming the equation to an equivalent one with eigenvalues in a favorable location or a smaller cluster. Even simple preconditioning, involving an approximate inverse obtained from the main diagonal of the matrix, has been shown to yield an improvement in efficiency over the conventional conjugate gradient algorithm for certain problems. Results from two iterative algorithms incorporating preconditioning, one a variation of the conjugate gradient method and the other a form of Chebyshev iteration, indicate that preconditioning can improve the rate of convergence significantly for electromagnetics applications.

THE SECANT-CORRECTOR SPECTRAL ITERATION METHOD

R.J. Middelveen and C.G. Christodoulou
University of Central Florida
P.O. Box 25000
Orlando, FL. 32816

J.F. Kauffman
North Carolina State University
P.O. Box 7911
Raleigh, NC. 27695-7911

In the past, the method of momments, the average boundary condition method, the spectral iteration approach, and the contraction-corrector spectral iteration method were widely used to solve the problem of scattering from infinite metallic gratings. The most efficient of these methods is the contraction-corrector spectral iteration approach. However, it was found that for some cases this method fails to converge. This behavior was attributed to the dependence of the method on the accurate estimation of complex numerical derivatives. To alleviate this problem, a new derivative-free technique has been developed. This technique, makes use of the secant method to obtain a new estimate of the electric field at each iterative step of the SIT method. The new method converges for gratings of any spacing, angle of incidence and polarization. This method can be applied to the problem of scattering from infinite gratings that are made of perfectly conducting strips, strips with finite conductivity, and strips made of different alloys. Applications and examples of this new numerical technique are presented and discussed. Furthermore, results and comparisons of this algorithm with other methods are included.

RESULTS ON THE INVERSION OF TOEPLITZ MATRICES FOR SOLUTIONS TO ELECTROMAGNETIC PROBLEMS

W. Ross Stone
IRT Corporation
1446 Vista Claridad
La Jolla, CA 92037

A Toeplitz matrix is a matrix in which the elements $T_{ij} = f(i-j)$. Such matricies are completely specified by a single row or column. Most electromagnetic scattering, diffraction, and radiation problems can be readily expressed in discrete, numerical form using Toeplitz matricies, because the Green's function appears as a convolution kernal in the integral formulation of these problems. For such formulations, inversion of a Toeplitz matrix is required to obtain a solution. "Classical" matrix inversion methods would require of the order of N^3 operations (multiplications and additions) for inversion of an N by N matrix. Recently, several new algorithms have become available which permit inversion of Toeplitz matricies in the order of N $\log^2 N$ operations, with order N storage. Of these, the algorithm by Kumar (Trans. ASSP, 33, 254-67, 1985) has the very desireable qualities of being noniterative and actually achieving close to the theoretical speed. Kumar's algorithm is based on developing a circulant matrix from the Toeplitz matrix, but the process used to extract the inverse of the Toeplitz from the inverse of the circulant is extremely complex. There are also no results available concerning the stability and/or accuracy of the result.

This paper presents several new algorithms which are also based on inverting a circulant matrix derived from the Toeplitz matrix. It is shown that although there is a large class of possible circulant matrices which can be derived from any given Toeplitz matrix, for certain of these the difference between the Toeplitz and the circulant is readily quantifiable and has other very useful properties. With the proper choice of the circulant the inverse of the Toeplitz can be recovered in a particularly simple fashion. It is shown that, for the Toeplitz matrices arising in problems with discrete data in a finite domain, the inverse of the Toeplitz matrix obtained by inverting a certain related circulant matrix can be exact (except for numerical errors). A byproduct of this algorithm is the result that, for many practical electromagnetic problems, the difference between the inverse obtained for a particular related circulant matrix and the Toeplitz matrix itself can be computed before inversion at insignificant computational cost, and can be used to form the circulant such that the difference is less than the desired precision of the result. This can eliminate the step of extracting the inverse of the Toeplitz matrix from the inverse of the circulant.

ON THE USE OF TRAVELLING WAVE BASIS FUNCTIONS

R.J. Pogorzelski
TRW Space and Technology Group
One Space Park
Redondo Beach, CA 90248

Many years ago it was shown that the current on a thin wire satisfies the Helmholz equation. (H.C. Pocklington, *Proc. Cambridge Phil. Soc.*, 9, 324, 1897.) This fact has since been exploited by a number of researchers in studying the scattering or radiation from a thin wire by expressing the current as a sum of three terms: two oppositely travelling waves and a known driven term having spatial frequency given by the projection of the propagation vector of the incident wave on the axis of the wire. (A. Sezginer and J.A. Kong,*Rad. Sci.*, 18, 639-649, 1983.) All of this earlier work suggests the use of travelling waves as basis functions in moment method solutions of one dimensional integral equations. Very recently, an entire domain travelling wave basis was used in Galerkin solution of the one dimensional integral equations arising in analysis of bodies of revolution. (L.N. Medgyesi-Mitschang and J.M. Putnam, *Nat. Rad. Sci. Mtg. Digest*, June 1984, Pg. 78.) (L.N. Medgyesi-Mitschang and J.M. Putnam,*No. Am. Rad. Sci. Mtg. Digest*, June 1985, Pg 64).

The present work concerns the use of a subdomain travelling wave basis in such problems. The current is expanded in basis functions consisting of the product of a travelling wave and a smooth subdomain envelope such as a Gaussian or a cubic spline. Galerkin's method is then used to obtain a set of simultaneous linear equations for the unknown coefficients. (It is interesting to note that the well known "Numerical Electromagnetics Code", NEC, uses a travelling wave basis with a pulse envelope and point matching.) A major concern pertaining to the practicality of such an approach is the efficiency with which the matrix elements can be computed. This computation involves two dimensional integration of highly oscillatory integrands which may exhibit highly peaked behavior. However, the use of the proposed basis permits the use of relatively long sub-sections and thus results in a much smaller system of equations; i.e., a much smaller coefficients matrix for a given size object relative to simpler bases. The relative matrix size advantage versus the integration complexity is addressed in this work.

ON THE VALIDITY OF TERMINAL PROPERTIES OF THIN-WIRE ANTENNAS COMPUTED USING THE NUMERICAL ELECTROMAGNETICS CODE (NEC)

Ben Halpern and Raj Mittra
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

In antenna engineering it is often necessary to compute certain parameters which are used to assess the input and radiative properties of antennas. Among these parameters are input impedance, directive gain, power gain, and efficiency, all of which are derived for a specified antenna geometry from a known feed network and the corresponding induced current over the antenna surface. The equations which govern the behavior of antennas are continuous mathematical operations which relate continuous currents on the antenna surface to a specified source field or feed. Since these equations cannot be solved analytically, they must either be discretized and solved numerically using a computer, or solved approximately using variational techniques. In either case, the solution obtained is an approximation to the original problem, and the figures of merit mentioned above will also deviate from their respective values. The purpose of this paper is to describe ways to minimize the difference between the computed and actual values of the aforementioned figures of merit for thin-wire antennas. It is shown that a code such as the Numerical Electromagnetics Code (NEC) of Lawrence Livermore National Laboratory is a powerful tool in the analysis of thin-wire antennas provided that the model is accurate and the results are interpreted properly.

The directive and power gains are directly related to the radiated or far field of the antenna and thus exhibit little variation from their true values when small computational errors are superimposed on the current. This is not always the case with the input impedance and radiative efficiency of antennas, as they depend highly on the terminal properties and near fields of the antenna as well. The subject of this paper is an assessment of the computational accuracy of the input impedance and radiative efficiency of thin-wire antennas using the Numerical Electromagnetics Code.

Alternate formulas for both the input impedance and the efficiency that are less sensitive to small variations in the current about its true value are presented. It is shown that when the modeled feed region is small, the computed current is nearly constant over the feed region, and the integrated near-electric field over the feed region equals the negative of the input voltage, the alternate expressions reduce to the simple forms used in NEC. It is highly recommended, therefore, that one should closely examine the computed current and near field over the surface of the modeled structure and then determine what simplifying forms, if any, are valid when computing the terminal properties of antennas.

A NUMERICAL APPROACH TO MODELING WIRES ATTACHED TO SURFACES

Donald R. Wilton and Shian-Uei Hwu
University of Houston, Houston,TX 77004

The problem of numerically modeling configurations of wires with attachment points on conducting surfaces has received the attention of several researchers. Recently, the attachment of wires to surface patch models has been considered. In a recent attempt to develop a scheme for attaching wires at triangle vertices in a triangular patch model, independent junction basis functions were used in each of the patches surrounding the attachment point. This presumably would allow modeling of the variation of the current about the base of the wire due to asymmetries in the structure, to the presence of structural edges or vertices at or near the attachment point, or to an inclination of the wire at the attachment point. However, it was found that the junction and the surface basis functions were almost linearly dependent on one another and unstable numerical solutions resulted. For the same modeling scheme, another recent approach eliminated this difficulty by assuming only a radial variation for the surface current around the base of the wire, but this scheme would not be expected to model wires near edges or vertices well. The basis functions used in both these approaches varied radially away from a triangle vertex as $1/r$ with an additive term to force the current density to vanish along the opposite triangle edge. The corresponding charge had a constant radial, but a cosinusoidal angular variation within a triangular patch.

In this paper, a new approach to attaching a wire to a surface modeled by triangular patches is proposed. First, the variation of the current about the base of the wire is determined *a priori* by solving a related magnetostatic problem in much the same way that the behavior of current near an edge is determined by solving a related wedge problem. The distribution so determined may then be used to appropriately weight the distribution of basis functions about the base of the wire, leaving only a single multiplicative contstant to be determined numerically. Secondly, a simpler basis function is proposed which has a constant charge density within a triangle and which can be expressed as a linear combination of an ordinary surface basis function and a function having the requisite $1/r$ variation. Significantly, the required moment matrix integrals associated with the new junction basis function within a patch can be expressed in terms of those associated with the surface basis functions in the patch plus a contribution of the magnetic vector potential associated with the latter term. A simplified approach for evaluating this vector potential integral, which has an integrand with up to two singularities, is presented.

APPLICATIONS OF THE FINITE ELEMENT METHOD FOR ELECTROMAGNETIC MODELING OF HIGH SPEED DIGITAL CIRCUITS

Z. Pantic, S. Castillo and R. Mittra
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

Electromagnetic modeling of high speed digital circuits has become increasingly important in recent years due to the large effective bandwidth at which these circuits operate. The problems of characterizing printed circuit transmission lines, printed circuit line discontinuities, and interboard connectors are all important sub-problems in the total model. The traditional numerical technique of applying the Method of Moments (MOM) to a boundary integral equation is not always easily adaptable to the solution of these problems. This is due to the complex geometries that some of these problems present and to the amount of computer memory needed to store the coefficient matrix generated from this technique.

The Finite Element Method (FEM) can easily be used on problems which have a complex geometry. The application of the FEM to the solution of partial differential equations results in a larger coefficient matrix than in the MOM formulation of boundary integral equations. However, the FEM coefficient matrix is rather sparse; hence, the storage required for this matrix is a linear function of the number of unknowns.

The FEM has been applied to printed circuit transmission lines of various cross sections with one or more conductors to solve for the capacitance and inductance matrices of the system as well as the per unit length conductance and resistance matrices for lossy systems. In the full wave case, FEM is used to derive an eigenvalue equation from which the modes of the system can be solved.

FEM is also being used to analyze connectors. The analysis involves solving Laplace's equation. From this solution, a lumped circuit is derived which is used in a transmission line program to simulate the effects of the connector.

The biggest problem in using FEM is that of mesh generation. The CAEDS Supertab pre-processor package is currently being used to generate meshes for both 2-D and 3-D problems. The user can define mesh densities, set boundary conditions, and assign properties to the various elements in the mesh. The mesh file generated by CAEDS is then used in a custom analysis program to solve for the desired quantities.

The analysis has been written for portability and has been run on the IBM-PC, the VAX 11/780 as well as the CYBER 175. Currently it is being adapted for use on the CRAY XMP/20 supercomputer.

A New Specctral Domain Approach for Microstrip Antenna Structrues

Y. Lin

Department of Electrical Engineering
University of Manitoba
Winnipeg, Manitoba, Canada R3T 2N2

Using the moment method a spectral domain analysis of basic microstrip antenna structrues is proposed in this paper. The set of convolution type integro-differential equations, which couples the interior and exterior fields over both conducting and dielectric interfaces is transformed into a set of algebraic linear equations by the Fourier transform. This set of functional equations is reduced to a matrix equation in a spectral domain using a moment method. The approach is then applied to both square and rectangular patch geometries and their near-field and far-field distributions are determined. The near- and far-field results are compared with the previous published results and with experimental data. The efficiency and the accuracy of the method for analysis of microstrip antennas is discussed. Detail of the method and its results will be discussed during the presentation.

PHILA. NORTH
B-5—DIFFRACTION AND SCATTERING
Chairman: D.G. Dudley
MONDAY-PM

THE BACKSCATTERED FIELD OF A THIN WIRE LOOP FOR E POLARIZATION

J. W. Burns and T.B.A. Senior
Dept. of Electrical Engineering and Computer Science
The University of Michigan
Ann Arbor, MI 48109

The problem considered is the determination of the backscattered field of a thin wire loop when illuminated by a plane electromagnetic wave whose electric vector is parallel to the plane of the loop. The problem has been previously analyzed by Kouyoumjian (Appl. Sci. Res. B 6, 165-179, 1956) using variational techniques and Weston (Res. Rep. No. 12, Univ. of Toronto, 1957) using eigenfunction expansions; however, both methods are feasible only when the electrical radius of the loop is small. For large loops, an appropriate method of finding the backscattered field is to use the geometrical theory of diffraction. Indeed, Keller and Ahluwalia (SIAM J. Appl. Math. 20, 390-405, 1971; Proc. IEEE 60, 1552-4, 1972) formulated a GTD solution, but certain second and higher order contributions were omitted.

To remedy this defect, the correct caustically matched second order GTD expression has been derived and compared with numerical data found using the NEC (Burke and Poggio, Interaction Note 363, 1977) and other computer programs. The improved GTD solution was found to be in excellent agreement with the numerical data for normal and near normal incidence on the loop, but at large angles of incidence a significant discrepancy was evident. Examination of the numerical data for edge-on incidence showed that the discrepancy is due to contributions from waves propagating around the loop in a manner not predicted by a GTD solution incorporating only edge-diffracted rays (Burns, Rad. Sci. Mtg., Vancouver BC, June 1985). Subsequent analysis of this problem for the case of H polarization, where the incident magnetic vector is parallel to the plane of the loop, resulted in empirical expressions for the velocity and decay of the circulating waves and a method of calculating their contribution to the far field (Burns and Senior, to be pub.).

Using the H polarization results and observations of the numerical data, a model for the circulating current is developed which consists of two waves coupled to the loop at the sides and propagating in opposite directions around the loop. The model of the circulating current is then used to calculate the contribution to the far backscattered field. When the circulating wave contribution is added to the uniform GTD solution , the resulting expression for the far backscattered field is in very good agreement with the numerical data for all angles of incidence and loop radii greater than about $\lambda/2$.

Scattering by a Finite Length Perfectly Conducting Flat Strip with Non-Parallel Edges

Philip J. Moser
Corporate Technology Center
Sperry Corporation
Reston, VA. 22091

Edge diffraction techniques have been used to analyze scattering from infinitely long conducting flat plates and rectangular plates. The same techniques can be used to describe the scattering from a plate whose front and back edges are not parallel. In the far field simple closed form solutions can be found which describe the single and double diffracted fields from this plate. For example the single diffraction fields at oblique incidence for the front and back edges are given in the frequency domain by the usual GTD edge diffraction term with: a) modifying phase factors arising from the finite plate length and widths; and b) a modulating sinc function term due to the varying plate widths. The double diffracted TE fields can be represented in a similar manner except the sinc function is replaced by the difference of two Fresnel integrals. The double diffracted TM fields must be derived from slope diffraction terms and are more complex than the TE equations but, nevertheless, reduce to closed form solutions. The double diffraction results can then be generalized into a recursion relation for inclusion of multiple diffraction and higher order effects. From the generalized multiple diffraction field equations resonance conditions can be found by phase matching the diffracted fields which propagate along the upper and lower surfaces of the plate between the edges. It will be shown that the resonance frequencies for these plates will no longer be discrete complex eigenfrequencies but will be bands of continuum frequencies. Simulation results for standard radar frequencies will be presented for plates whose dimensions approximate known aircraft wings.

SPECTRAL METHOD FOR MULTIPLE EDGE DIFFRACTION BY A FLAT STRIP

H. Shirai and L.B. Felsen
Department of Electrical Engineering and Computer Science
Polytechnic Institute of New York
Farmingdale, N.Y. 11735

A spectral iteration scheme is employed to analyze time-harmonic and transient scattering of an E or H polarized incident plane wave by a perfectly conducting plane strip. The scattered field is synthesized by successive interactions between the edges, with each interaction modeled by half plane diffraction. The plane wave spectrum generating a particular order of diffraction consists, in addition to the incident plane wave excitation, of a portion determined from the previous diffraction. The multiple integral spectral representations constructed in this manner satisfy the edge condition, and they are in a form suitable for inversion into the time domain by the modified Cagniard-DeHoop method. Asymptotic reductions for special cases yield agreement with results from other methods, when available. Numerical calculations including up to triple diffraction have been performed for H and E polarized impulse and Gaussian pulse scattering. The results are clearly seen to repair the deficiencies of wavefront approximations at longer observation times, and from comparison with data generated independently by eigenfunction expansion, they describe accurately the total scattered response, owing to the high damping rate of higher order diffractions.

FREQUENCY DEPENDENCE OF SCATTERING FROM A WEDGE WITH A ROUNDED EDGE

K. M. Mitzner and K. J. Kaplin
Advanced Systems Division
Northrop Corporation
Pico Rivera, California 90660

Using an integral equation technique, the far-field backscatter was calculated for an infinitely long perfectly conducting wedge with a rounded edge which is illuminated by a plane wave with E parallel to the edge. It was verified that the scattered field is given at low frequency by Keller's sharp wedge theory and is given at high frequency by physical optics for a cylinder with the same radius of curvature as the rounded edge. At intermediate frequencies, calculated data for various wedge angles showed a smooth monotonic transition in magnitude and phase between these two limiting cases.

It was then shown that the expression

$$E = (E^2_{low} + E^2_{high})^{1/2},$$

where E_{high} is the high frequency physical optics solution and E_{low} is Keller's result for a wedge with its edge at the specular point on the rounded edge, is an accurate approximation for all frequencies, including the transition region.

This equation can be applied formally to a variety of wedge problems for which the high and low frequency limiting behaviors are known. It is reasonable to expect the result to be a good approximation for many cases in which the transition is smooth.

APPROXIMATE EDGE REPRESENTATION FOR COATED STRIPS

L. N. Medgyesi-Mitschang and J. M. Putnam
McDonnell Douglas Research Laboratories
P.O. Box 516
St. Louis, MO 63166

A detailed study is made of the currents near the edge of coated strips and the resulting scattered fields are computed. In this analysis the strip is electrically large in relation to the coating thickness. As is well-known, the field singularities for components perpendicular to an edge follow a $(\frac{1}{r})^n$ law. Meixner (Trans. AP-S 20, 442-446, 1972) originally investigated the singularities at dielectric-metal and dielectric-dielectric wedge-like interfaces. Recently, Van Bladel (Trans. AP-S 33, 450-455, 1985) quantified the dependence of n as a function of the dielectric and magnetic contrast and the included (acute or re-entrant) wedge angle. In the present analysis, the physics of the problem is described in terms of coupled surface integral equations. Approximate edge representations for the equivalent surface currents are proposed in terms of the Van Bladel solutions and are compared for various coating thicknesses and material contrasts. The Galerkin solutions are also correlated with recent experimental measurements.

UNIFORM EVALUATION OF THE SURFACE WAVE DIFFRACTION BY AN IMPEDANCE WEDGE AND ITS APPLICATION TO A STRIP

M. I. Herman and J. L. Volakis
Radiation Laboratory
Department of Electrical Engineering and Computer Science
The University of Michigan
Ann Arbor, Michigan 48109

Previous uniform solutions for the diffraction by an imperfectly conducting wedge (R. Tiberio, IEEE Trans., AP-S, 33, 867-873, 1985) have not included a uniform evaluation of the surface wave contribution which can be rather significant when it exists. In this presentation a method will be discussed for the derivation of a uniform diffraction coefficient including the surface waves. This technique first involves the subtraction and addition of each singular term in the diffraction integral (P. C. Clemmow, The Plane Wave Spectrum Representation of Electromagnetic Fields, Pergamon Press, 1966). The integrand is thus subdivided into singular and non-singular parts. The integrals associated with the singular terms are evaluated exactly and the remaining are evaluated asymptotically. In most cases the contribution of the latter terms are negligible. It is further noted that the above procedure is rather general and can be applied to cases where several singularities may exist.

The above solution is applied to the scattering analysis of a thin dielectric strip by considering only the electric current contributions associated with the impedance half plane (T.B.A. Senior, Rad. Sci., 10, 645-650, 1975). In this analysis all surface wave contributions due to edge interactions are included in a self-consistent manner and a slope diffraction component is included. Results obtained compared favorably with the moment method solution (J. H. Richmond, IEEE Trans. AP-S, 33, 64-68, 1985).

A UTD Formulation for the EM Diffraction by a Wedge With Impedance Faces and with Included Angles Equal to 0, π/2 and π (Oblique Incidence)

Roberto G. Rojas
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

A Uniform GTD (UTD) formulation is presented for the electromagnetic diffraction by a wedge with impedance faces and with included angles equal to 0 (half-plane), π/2 (right-angled wedge), and π (two-part planar surface). The solution is based on the Generalized Reflection Method considered by Vaccaro (AEU, Vol. 34, pp. 493-500, 1980). Vaccaro expresses his final solution in the spectral domain, however, he does not perform any asymptotic evaluation of his results which is done here. In a second paper (Optica Acta, Vol. 28, pp. 293-311, 1981), Vaccaro employs the Oberhettinger approach to obtain a uniform asymptotic approximation to the spectral integral for the special case of the right-angled wedge excited by an incident plane wave. This leads to a solution which exhibits the Uniform Asymptotic Theory (UAT) format where the "so called" transition function in the uniform solution is additive rather than multiplicative (as in the UTD). In this paper, both the plane and surface wave incidence cases will be considered. One big advantage of the present solution is that it can be expressed in a very compact matrix notation. Furthermore, in contrast to previous work, the asymptotic evaluation will be performed taking into account the presence of the surface wave poles (in addition to the geometrical optics poles) in the vicinity of the saddle point. Some numerical results will be presented and compared with previously obtained solutions.

UNIFORM ASYMPTOTIC SOLUTION FOR THE DIFFRACTION OF A PLANE WAVE
BY A LINE OF DISCONTINUITY IN THE SURFACE CURVATURE
OF A CONVEX SURFACE WITH COMPLEX IMPEDANCE

by

Frédéric A. Molinet
Société MOTHESIM
La Boursidière
RN 186 , 92357 LE PLESSIS-ROBINSON , FRANCE

We present a uniform asymptotic solution for the diffraction of a plane wave or a local plane wave, by a line of discontinuity in the surface curvature of a convex surface, the properties of which are difined by a complex surface impedance. The solution which has been established is valid in the transition region of the reflected rays and tends to the solution of KAMINETZKY and KELLER outside the transition region. The approach which has been followed can be divided into three steps :

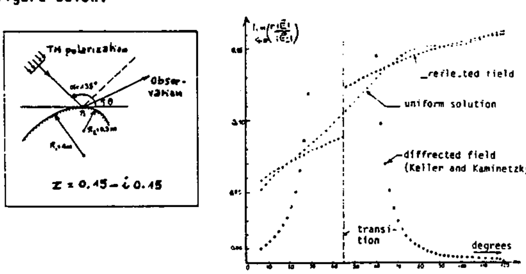
In a first step, a uniform asymptotic solution has been established in the vicinity of the line where the surface curvature is discontinuous by introducing stretched coordinates and applying the Boundary Layer Method.

In a second step, by identifying the terms of the solution and the geometrical parameters which are contained in it, and especially by identifiying the first two terms of the LUNEBURG - KLINE expansion of the reflected field, the general structure of the solution in the far zone of the boundary layer, allowed us to suggest the structure of the solution outside the boundary layer.

In a third step, a procedure has been established for the construction of a uniform asymptotic solution outside the boundary layer when the general structure of this solution and the expression of the non uniform solution are known.

The continuity of the asymptotic solution through the shadow boundary of the reflected field has been verified numerically and analytically by applying it to a two-dimensional form composed of two circular cylinders with different radii, connected along a generatrix in such a way that the tangent plane be continuous.

Numerical results will be presented. A typical result is illustrated on the figure below.



SCATTERING FROM IRREGULAR-EDGED SURFACES

J. M. Putnam and L. N. Medgyesi-Mitschang
McDonnell Douglas Research Laboratories
P.O. Box 516
St. Louis, Missouri 63166

A rigorous formulation is presented for electromagnetic scattering from finite translated surfaces with irregular edges. The basis of the formulation is the electric-field integral equation (EFIE), solved by the Galerkin method. The surface currents on the body are decomposed into parallel and perpendicular components defined in terms of an edge-slope dependent vector field. Both entire and subdomain Galerkin expansions, for the currents in terms of these components, are then used to effect a solution. This expansion relaxes to the proper edge conditions everywhere for arbitrarily polarized incident fields and results in simplifying symmetries for the system matrix. This approach is shown to be highly advantageous for irregular-edged surfaces since the expansion with proper normalization implicity adjusts to changing surface dimensions. An earlier investigation has illustrated the use of this approach for circular ducts with irregular edges (L. N. Medgyesi-Mitschang and J. M. Putnam, Proc. Nat. Radio Sci. Meeting, 64, 1985).

The present formulation and analysis applies to circular and noncircular configurations as well as flat or curved open translated surfaces. Various limiting cases will be discussed, such as application of the method to circular and square ducts with nonparallel edges, and general trapezoidal plates (flat or curved). The convergence of the solutions will be examined as a function of expansion terms in the Galerkin representation, degree of edge irregularity (i.e., edge-slope), and dimensions of the surfaces. Because existing analytical/numerical methods cannot effectively treat the foregoing class of problems, the present calculations will be compared with new experimental data obtained for flat and duct-like bodies.

SALON 3/4
B-6—INVERSE SCATTERING I (PROFILE INVERSION)

Chairman: D. Jaggard
MONDAY-PM

A NUMERICAL SOLUTION TO THE INVERSE SCATTERING PROBLEM ASSOCIATED WITH THE ZAKHAROV-SHABAT COUPLED-MODE EQUATIONS

P.V. Frangos and D.L. Jaggard
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Many problems in the areas of electrical engineering and applied science, such as the synthesis of non-uniform transmission lines or corrugated waveguide filters, are reducible or are closely related to the inverse scattering problem associated with the Zakharov-Shabat system. This system has the form of coupled mode equations with varying coupling as given by

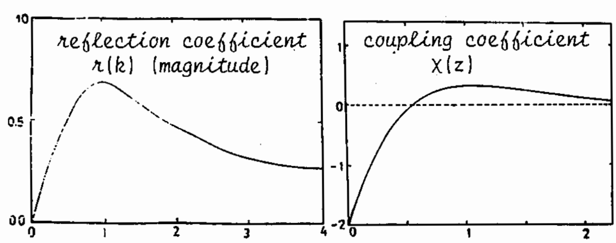
$$F'(z) + ikF(z) = \chi(z)\, B(z)$$

$$-B'(z) + ikB(z) = \chi^*(z)\, F(z)$$

Here F(z) and B(z) are the two components of the coupled modes, $\chi(z)$ is the unknown coupling coefficient to be determined and k is the phase shift. The known data is the reflection coefficient $r(k) = B(z)/F(z)$ defined at some boundary, say z=0.

Here we develop a numerical solution to this problem based on the Gel'fand-Levitan-Marchenko (GLM) inverse scattering method. That is, $\chi(z)$ is found from a knowledge of r(k). This method, which is exact in nature, involves the solution of coupled integral GLM equations which are solved numerically by leapfrogging in space and time. In addition, an iterative procedure can be invoked to provide extreme accuracy. Analytical solutions can also be found for restricted classes of reflection data.

A comparison of analytical and numerical examples demonstrate the accuracy of the latter. We note that the numerical method proposed here is efficient and apparently not restrictive with respect to the form of the reflection coefficient data. Below is shown reflection data and a corresponding reconstructed coupling coefficient. The numerical reconstruction is not graphically distinguishable from the exact analytical solution.



APPLICATION OF BOUNDARY-LAYER THEORY TO INVERSE SCATTERING

H. D. Ladouceur and A. K. Jordan
Naval Research Laboratory
Washington, DC 20375-5000 USA

In previous work (J. Optical Soc. Am. A, vol. 2, p. 1916; 1985), we have developed a renormalization technique for the inverse scattering problem associated with electromagnetic waves reflected from inhomogeneous dielectric regions. This renormalization technique relies upon the assumption that the inhomogeneous dielectric region is a continuous and slowly-varying function of spatial position. However, any finite object or surface in free space will always present a discontinuity to an incident electromagnetic wave. In order to extend the renormalization technique to such discontinuous structures, we have applied boundary-layer theory to the renormalization of the electric field within the structure. The resulting electric field is represented as a composite expansion, which is uniformly valid throughout the entire interior region of the structure. The field near the discontinuity at the surface is dominated by the boundary-layer solution, which rapidly decays as a function of depth into the interior of the region. The resulting field in the "deep" interior of the structure is assumed to be given by a slowly-varying electric field. The composite expansion for the electric field provides a kernel to reconstruct discontinuous dielectric profiles from given reflection coefficients. Several numerical examples of this technique are given.

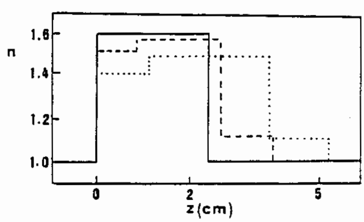
NONLINEAR INVERSION TECHNIQUES FOR STRATIFIED DIELECTRICS: THEORY AND EXPERIMENT

D.L. Jaggard, Y. Kim, K. Schultz and P.V. Frangos
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

It is well known that for dense dielectrics and/or for those of large electrical dimension, the linear relation between the refractive index and the reflection coefficient breaks down. This problem has been circumvented in the one dimensional case by use of exact or highly accurate approximate inversion techniques. Here we examine two of these techniques and implement them with swept frequency microwave reflection data from lossless dielectric slabs.

The first technique is an exact method based on the integral equation of Balanis. This equation can be solved analytically for some reflection data and numerically for other data as we have shown previously. The second technique is an approximate method based on a nonlinear renormalization of the Riccati equation which relates the refractive index profile to the local reflection coefficient. We have provided a method for inverting this equation so that the inverse problem can be solved for the refractive index when the reflection data is available.

Below are shown experimental results based on the second technique using bandlimited data (6.1-17.1 GHz) for a 2.54 cm plexiglass slab with refractive index n=1.6. In the figure is shown the application of the approximate nonlinear renormalization technique (dashed line), the linear (Born) reconstruction (dotted line) and the desired result (solid line). Here z is the coordinate from the front face of the slab. Note that the nonlinear renormalization technique significantly decreases both the amplitude and distance errors characteristic of linear techniques.



THE DETERMINATION OF CONSTITUTIVE PARAMETERS FROM THE REFLECTION AND TRANSMISSION OF A SPHERICAL WAVE ILLUMINATING A MATERIAL SLAB

F. B. Gross, B. W. Kwan
The Florida State University
Department of Electrical Engineering
102 Education Building
Tallahassee, FL. 32306

It is of practical importantance to determine the electrical and magnetic properties (permittivity and permeability, respectively,) of arbitrary materials. Since these properties are virtually impossible to predict, they must be determined experimentally. Time domain measurement techniques for closed systems have been investigated (B. Kent, Avionics Laboratory, WPAFB, OH, August 1981) up to the K-band (18-26 GHz). In this paper, a frequency domain measurement technique is developed for an open system. It is shown how to obtain the permittivity and permeability from the measurement of the scattering parameters of an unknown planar material slab illuminated by a spherical wave. This involves an appropriate frequency sampling technique, and careful treatment of both the reflected and transmitted waves. Measurement results are presented over a frequency range of 2-18 GHz.

A STUDY OF THE ITERATIVE DISTORTED BORN INVERSION FOR PROFILE RECONSTRUCTION

E. Y. Chow, T. M. Habashy*, and W. C. Chew***

* Schlumberger-Doll Research
Old Quarry Road
Ridgefield, CT 06877-4108

** Department of Electrical and Computer Engineering
University of Illinois
1406 W. Green St.
Urbana, IL 61801

An interative inversion procedure that employs the distorted Born approximation of the field equations (in source-type integral form) at each iteration has been proposed in the literature for permittivity and conductivity profiles reconstruction. It was applied using noise-free simulated data in planar and cylindrical geometries with good results. Since there are several degrees of freedom in the implementation of this inversion procedure (to be discussed below), reconstruction performance is heavily dependent on the specific implementation. In this paper we will examine the behavior of the inversion procedure as a function of implementation.

The various degrees of freedom in implementing the distorted Born inversion procedure are associated with the forward model, the iteration scheme, and the measurement set. Since profiles have to be discretized for computation, one of a variety of discrete forward models, depending on the discretization scheme, can be used in the reconstruction. Together with finite precision arithmatics, this results in an effective forward model that may be markedly different from the model used to simulate the data. At each iteration step, an optimization problem with several built-in tuning parameters needs to be solved. Together with the choice of these tuning parameters, the choices of initial guess profiles and a convergence (stopping) criterion generally have a significant effect on the result of the iterations. In a realistic application, measurement data are usually incomplete (i.e. data available at finite number of frequencies and/or receiver locations) and noisy. Inversion performance is often sensitive to the usage of such imperfect data. The goal of this paper is to explore the effect of the above implementation considerations on the performance of the distorted Born inversion procedure in a medium with cylindrical stratification (i.e. the permittivity and conductivity profiles vary only in the radial direction).

SIMULTANEOUS INVERSION OF PERMITTIVITY AND CONDUCTIVITY PROFILES OF A CYLINDRICALLY STRATIFIED MEDIUM USING THE FAST CHOLESKY ALGORITHM

*T.M. Habashy** *and R. Mittra***
* Sclumberger-Doll Research
Old Quarry Rd
Ridgefield, CT 06877-4108
** Department of Electrical and Computer Engineering
University of Illinois
1406 W. Green St.
Urbana, IL 61801

The problem of profile inversion of a layered medium is an important one and has received considerable attention in the past two decades. However, most of the inversion schemes deal with the reconstruction of either the permittivity or the conductivity profile of a <u>planar</u> stratified medium, from the reflection data gathered with an illuminating plane wave. Little, if any, has appeared in the literature on the problem of simultaneous reconstruction of permittivity and conductivity profiles of a lossy dielectric medium, particularly for the case of a cylindrically stratified medium excited by a dipole-type source.

In this paper we address this problem using the fast Cholesky algorithm, which was employed recently in connection with the inversion of the acoustic wave impedance of a planar stratified medium excited by an impulsive, planar, acoustic wave (A.E. Yagle and B.C. Levy, J. Acoust. Soc. Am. 76-1, 301-308, 1984). In this paper we consider the source to be of dipole-type, one that generates only a TE-polarized wave. The data needed to carry out the inversion is generated from the tangential components of the electric and magnetic fields at the surface, measured as a function of time. This data is preprocessed using a Radon transform in order to obtain a system of two wave components necessary for the development of the fast Cholesky algorithm. Another feature of this work is that it is capable of handling either an impulse or a step excitation, whereas the fast Cholesky algorithm has been applied in the past only with an impulsive-type source.

A REGULARIZATION SOLUTION TO THE INVERSE BLACKBODY PROBLEM

D.L. Jaggard and X. Sun
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

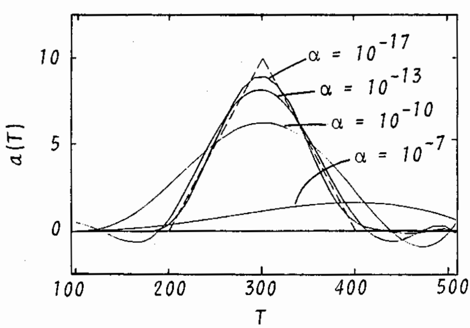
The inverse blackbody radiation problem is concerned with the determination of the temperature distribution of blackbody sources from remote spectral radiation measurements. That is, given the total spectral brightness $W(\nu)$ as a function of frequency ν, one is to determine temperature distribution $a(T)$ as a function of temperature T. The quantities $W(\nu)$ and $a(T)$ are related by an integration over the Planck distribution as given by

$$W(\nu) = \frac{2h\nu^3}{c^2} \int_0^\infty [e^{h\nu/kT} - 1]^{-1} \, a(T) dT$$

where h and k denote Planck's and Boltzman's constants, respectively, and c is the speed of light.

The above equation is a Fredholm integral equation of the first kind which is notoriously difficult to invert numerically due to the ill-posed nature of the problem. This implies that one or more of the problems of existence, uniqueness or instability plague the solution. Here we show that the solution exists, that it is unique and that the ill-posedness is due to instability. Through the use of a regularization procedure this latter problem is addressed and stable solutions are reconstructed. Practical matters of sampling density, limited data and noise are also considered.

Below are shown several regularized temperature reconstructions (solid lines) for various values of the regularization parameter α. The dashed line indicates the desired solution. Here α is a trade-off parameter between fidelity (α small) and smoothness (α large). Without regularization, the numerical solutions are nonsensical.



WYNDHAM C
B-7—NUMERICAL METHODS II

Chairman: D.R. Wilton
TUESDAY-AM

ON THE APPLICATION OF THE "COSMIC CUBE" CONCURRENT PROCESSOR TO MOMENT METHOD PROBLEMS

M. P. Hurst and I. K. Strother
TRW Space and Technology Group
One Space Park
Redondo Beach, CA 90278

The speed and storage capacity of digital computers has increased geometrically since their introduction, but fundamental limits exist and will be approached in the not too distant future. Concurrent processing, i.e., the coordinated use of many processors simultaneously, offers the possibility of extending computing power beyond these limits in the future and provides a means of reducing computing costs in the present. One particular architecture known as the Cosmic Cube has been developed at Caltech and successfully applied to a diverse assortment of scientific computing problems (C. L. Seitz, *Communications of the ACM*, Vol. 28, pp. 22-33, Jan., 1985). This paper discusses the application of a commercial version of the Cosmic Cube (the Intel iPSC) to the most common numerical method used by researchers in electromagnetics, viz., the method of moments.

In a typical moment method problem the bulk of computational effort is spent filling the coupling matrix, and success in using the Cube hinges upon distributing this task among the processors such that overhead and duplication of effort is minimized, and concurrency is maximized by balancing the computational load between processors. If each matrix element is calculated independently this can be accomplished by simply assigning an equal number of elements to each processor. In a typical application, however, there are symmetries which can be exploited and factors and terms common to several matrix elements, and an efficient code must take advantage these facts. The goal in distributing the element computations is, therefore, to group those elements with common terms and factors on a single processor, where possible, and on a neighboring processor otherwise. Fortunately, matrix elements which share intermediate results are often near neighbors in the coupling matrix, and by arranging the processors in a two-dimensional grid a direct mapping can be made which achieves the above goal. The particular example to be discussed in the presentation is a derivative of the Mautz-Harrington body of revolution code (J. R. Mautz and R. F. Harrington, Tech. Rept. No. TR-77-2, Syracuse University, Syracuse, Feb., 1977) which the authors were able to adapt to run on the iPSC with minimal modification to the matrix filling algorithm. Comparisons with computations performed on a conventional sequential machine will be made in the presentation.

RADIATION AND SCATTERING FROM ELECTRICALLY SMALL CONDUCTING BODIES OF ARBITRARY SHAPE ABOVE AN INFINITE GROUND PLANE

Ercument Arvas
Rochester Institute of Technology
Rochester, NY 14623

Roger F. Harrington and Joseph R. Mautz
Syracuse University
Syracuse, NY 13210

A simple moment solution is given for low frequency electromagnetic scattering and radiation problems. A small perfectly conducting body of arbitrary shape is assumed to be placed on or close to an infinite ground plane. The dynamic problem is approximated by two corresponding electrostatic and magnetostatic problems, and each static problem is then solved using the Method of Moments. The surface of the perfectly conducting scatterer is modeled by a set of planar triangular patches. Pulse expansion and point matching testing are used to compute the charge density in the electrostatic problem. For the magnetostatic problem a set of solenoidal vector expansion functions is used. The induced dipole moments are computed from the induced charge and current densities. The scatterer is assumed to be illuminated either by an incident plane wave or by a slowly oscillating dipole placed on the scatterer. Scatterers of various shapes are studied. Specifically a sphere and a square plate above (but close to) the ground plane are considered. From the computed induced dipole moments for a square plate perpendicular to the ground plane, it was concluded that the magnetic (electric) polarizability of two such square plates (apertures in an infinite conducting screen) is larger by about nine percent than the sum of their individual polarizabilities .

Special attention is given to a conducting box on the ground plane. First the box is assumed to be illuminated by a plane wave at grazing incidence and the induced dipole moments are computed. The scattered field is assumed to be produced by these induced dipoles which are placed on the ground plane. Then the box is assumed to have some internal sources and a small slot in its surface. To investigate the efficiency of the narrow slot in transmitting energy outside , the slot is modeled by a slowly oscillating magnetic dipole tangent to the surface of the box when the slot is shorted. It is observed that radiation from a narrow slot will be minimal if the slot is on a side face of the box and is oriented perpendicular to the ground plane.

Since the two static problems are decoupled and the quantities involved in the computations (such as the moment matrix elements) are real, the present method is more efficient, in terms of computer storage and time, than an EFIE method of solution which uses the same patching scheme. Also the present method gives more accurate results as the frequency gets smaller and smaller.

APPLICATION OF AN HYBRID-ITERATIVE TECHNIQUE TO A PERFECTLY CONDUCTING CUBE

R. P. Penno, P. K. Murthy and G. A. Thiele
Graduate Engineering and Research
University of Dayton
Dayton, Ohio 45469

An hybrid-iterative approach to solving the MFIE for the surface current density is applied to the case of a three-dimensional body, specifically, a cube. In this method, the currents on the surface of the cube are modeled as the superposition of many right-angled wedge currents. Initially, these component currents are available in closed form as described by Murthy and Thiele [P. K. Murthy, G. A. Thiele, "Non-Uniform Current on a Wedge Illuminated by a TE-Plane Wave," IEEE Trans. Antennas Propagation (to appear)]. For regions located approximately one-half wavelength or farther away from the vertex, these currents describe the current density with sufficient accuracy. Beyond one-half wavelength of each vertex, however, the wedge diffraction current dominates the vertex diffraction current. Close to the vertex, then, the MFIE is applied using the closed form wedge current approximation as initial currents. The iteration process described by Murthy, et. al. [P. K. Murthy, G. A. Thiele and K. C. Hill, "A Hybrid Iterative Method for Complex Scattering Problems," IEEE Trans. Antennas Propagation, (to appear)] produces refined or corrected values of the current density. Due to the accuracy of the initial currents used, the convergence is rapid.

It is straightforward to compute the radar cross section (RCS) using the calculated surface current density of the cube. This RCS is then compared with experimentally-derived data. Specifically, the cases of a cube whose sides are three to five wavelengths long are considered where illumination is broadside to a cube face. This will be extended to oblique incidence. Finally, it is expected that this technique will be extended to cubes of arbitrarily large side length.

A COMPARISON OF THREE GALERKIN SOLUTIONS FOR THE DISPLACED RECTANGULAR WAVEGUIDE JUNCTION

Robert W. Scharstein
General Electric Company
Radar Systems Department
Syracuse, NY 13221

Arlon T. Adams
Department of Electrical and Computer Engineering
Syracuse University
Syracuse, NY 13210

The integral equation for the aperture field at the junction between two rectangular waveguides displaced in the E-plane, H-plane, or both planes is approximately solved by Galerkin's method. The aperture field is projected onto a finite set of three different function spaces; sub-domain pulses, trigonometric waveguide modes that fit the rectangular aperture shape, and weighted Gegenbauer polynomials. The Gegenbauer polynomials are pre-conditioned to satisfy the edge condition at the 90° aperture edge through the weighting factor (A.M. Lerer, V.P. Lyapin, G.P. Sinyavskii, Radiofizika, Vol. 25, No. 8, 1982 and J.D. Hunter, IEEE MTT, Vol. 32, No. 4, 1984).

The elements of the aperture admittance matrix are expressed as infinite summations over waveguide modes of the inner products between aperture functions and waveguide modes. These infinite series must be approximately summed and not truncated, to avoid the 'relative convergence' problem. The numerical convergence properties of the three sets of basis functions are studied. Resultant aperture field distributions, equivalent circuits and scattering parameters are presented for dominant mode incidence. Experimental scattering parameters are also presented for comparison.

NUMERICAL SOLUTIONS OF SURFACE INTEGRAL EQUATIONS FOR INDUCED EM FIELDS IN BIOLOGICAL BODIES

Xiaoyi Min, K.M. Chen and B. Drachman*
Dept. of Electrical Engr. & Sys. Science, Dept. of Mathematics*
Michigan State University, E. Lansing, Michigan 48824

Consider a biological body being exposed to an incident electromagnetic wave. When the medium wavelength of the incident EM wave is small compared with the dimensions of the body, the induced EM field concentrates mainly in the surface layer of the body due to a small skin-depth. To quantify the induced EM field for this case, some surface integral equations for the induced E and H fields just inside the body surface are derived in terms of the incident E and H fields. The numerical solutions for these integral equations involve the solution of a large system of linear equations or a large matric problem.

With a super computer (Cyber 205), several numerical methods are investigated for the purpose of solving the surface integral equations. These methods include the conjugate-gradient method, the Gauss-Seidel method and the Jacobi method. Some simple problems are solved first with these methods. The computation time required for each method is compared. The most efficient method is then used to solve the surface integral equations for the induced EM fields in the biological bodies.

To improve the accuracy of numerical results, efforts are made to choose proper basis functions to represent the induced EM field in each partitioned surface cell. The two-dimensional Lagrangian linear basis functions are used to provide the continuity of the EM field, in both normal and tangential components, between adjacent cells. A set of basis functions introduced by Rao et al. (IEEE/APS, 3, 409-418, 1982) is also used. This set of basis functions is suitable for use with triangular patch modeling and it provides the continuity of the normal components of both induced electric and magnetic surface currents.

NUMERICAL SOLUTION OF *TE* SCATTERING BY INHOMOGENEOUS TWO-DIMENSIONAL COMPOSITE DIELECTRIC/METALLIC BODIES OF ARBITRARY CROSS SECTION

Deborah Kessler Langan, NASA Johnson Space Center, Houston, TX 77058
Donald R. Wilton, University of Houston, Houston, TX 77004

In this paper the scattering of composite two-dimensional metallic/dielectric bodies of arbitrary cross section under *TE* polarized plane wave illumination is considered. The volume polarization current is numerically determined in the dielectric material while the induced surface current is found on metal surfaces. The relative location and cross section of the cylindrical dielectric material and the metal surfaces is completely general; metal surfaces may be embedded in, placed on the surface of, or located exterior to the dielectric material. A volume polarization current integral equation formulation allows inhomogeneous material to be treated. Enforcing the E -field boundary condition on metallic surfaces also permits either open or closed metallic surfaces and junctions of such surfaces to be treated.

The cross section of the dielectric portion of the cylindrical structure is subdivided into triangular regions in each of which the conductivity and permittivity are assumed constant. Any metallic surfaces within the dielectric region are assumed to coincide with triangle edges, resulting in a piecewise linear model of the metallic surface cross section. Use of potential integral representations of the scattered field in the defining equation for the volume polarization current and in the E -field boundary condition on the metallic surfaces yields a pair of coupled integral equations for the induced current density. The numerical modeling of the polarization current in the dielectric region and the integral equation testing procedure is essentially identical to an approach reported earlier. The principal difference is that for metallic edges within the dielectric region, the polarization currents on opposite sides of such edges are independent. On the metallic surfaces, the numerical approach parallels that of the electric field integral equation. Also, the metal surface junction treatment essentially parallels that used in wire junction problems. An important feature of the approach is that basis functions are chosen which automatically incorporate the correct discontinuity conditions on normal components of polarization current at media interfaces. Results for a number of sample cases are presented and, where possible, are compared with solutions of canonical problems.

IMPLEMENTATION OF THE NUMERICAL ELECTROMAGNETIC CODE(NEC) FOR MODELING THE VOR NAVIGATION SYSTEM IN THE PRESENCE OF PARASITIC SCATTERERS

Kent A. Chamberlin
University of New Hampshire
Dept. of ECE
Durham, NH 03824-3591

Paul R. Barre'
Ohio University
Dept. of ECE
Athens, OH 45701

A computer model has been developed that estimates bearing error for a VOR airborne navigation system operating in the presence of small, parasitic scatterers such as antennas, antenna masts, and guy wires. This model, which is written in VMS batch commands and FORTRAN 77, interacts with an unmodified version of NEC-2 to obtain pertinent scattered-field data. These data are then used to calculate the composite field, and indicated bearing, at the airborne receiver location. Comparisons of modeled data with measured data indicate that this modeling approach is valid. The puropse of thispresentation is to give some of the insights gained while working with NEC for this type of application. The work discussed here was funded by the Federal Aviation Administration under Contract DTFA01-85-Y-01020.

The azimuth angle of an aircraft with respect to a VOR station is determined by the phase of the received audio sinusoid generated by a limacon pattern that rotates in space due to appropriate time-varying phasing between four Alford loop antennas. To model the effects of scatterers on system accuracy, each loop antenna is modeled alone in the presence of the scatterer using NEC and field data are recorded for a far-field orbit around the source-scatterer configuration; this process is repeated for each of the four loop antennas thus providing complete information about complex path loss between each loop antenna and the observation point in the presence of the scatterer. The received audio waveform is then constructed at each observation point by applying the appropriate modulation to each of the loop antennas, adjusted by the complex loss values given by NEC. The phase and distortion of the received audio waveform is determined using a Fast Fourier Transform algorithm.

The key points to be addressed include approximations for modeling the Alford Loop antennas, which involves attempts at surface patch excitation, representations of various parasitic scatterers and the ground plane, model diagnostics, and comparisons of modeled and measured data.

MODIFICATION OF THE DUAL-FINITE-ELEMENT METHOD IN ELECTROMAGNETISM : UPPER AND LOWER BOUNDS TO THE CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINES.-

E. MORENO, J. RIVAS and J.L. REBOREDO
Dpto. Electricidad y Magnetismo
Facultad de Física
Universidad de SANTIAGO DE COMPOSTELA
SPAIN.

ABSTRACT :

Prof. Hammond has already discussed the physical bases necessary to establish a dual-variational method in problems of electromagnetics fields (Clarendon-Press, Oxford,1981). Later, this method was complemented by the finite-element method (IEE Proc.,130,A,3,105-111,1983). Penman and Fraser have carried out mathematical studies on magnetic problems (IEEE trns. on Magn. 18,2,319-324,1982). A modification of the dual-finite-element method used to calculate energy parameters (R,L,C) is presented. This modification consist of a previous transformation of single connected zones to the other multiply connected equivalents,to which the duality is applied alternatively, with a resulting analitic and computational simplication.

The described method is used to calculate the characteristic impedance of transmission lines (TEM); energy functionals which limit the approximations are analysed. The lagrange system is obtained topologically. The application of the proposed method to the calculation of monodimensional systems one may rapidly obtain an excellent approximation, even to the exact value. In systems of more than one dimension the problem remains the problem of confidence limits for the upper and lower bounds. However, better results are achieved than ordinary methods.

The paper also attemps to simplify the essential steps of pre-processing of data while maintaining flexibility of the method.

The main emphasis of the paper is the new method : we have obtained a more convergent result with a reduction in computational time. The application of the method to non-linear systems is also a future possibility.

FINITE ELEMENT ANALYSIS OF THE COUPLING BETWEEN A DIELECTRIC RESONATOR AND A TRANSMISION LINE

F. Hernández-Gil*, J. Pérez**

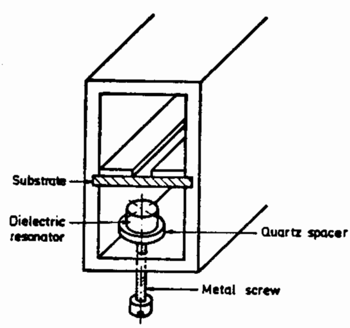
* R&D Dpt., Telefónica, Lérida 43, 28020 Madrid, Spain.
** Microwave Dpt.,E.T.S.Ing.Telecomunicación,28040 Madrid,Spain.

A theoretical method to calculate the external quality factor of an axisymmetric dielectric resonator coupled to a transmission line has been developed. The finite element method was used to solve both the transmission line and the dielectric resonator. This method provides flexibility in the analysis of both structures.

The resonant frequency and the field distribution of the resonator are calculated using a finite element procedure (F.Hernández, 1985 MTT-S, pp.485-488). The field distribution and the propagation constant of the transmission line are calculated at the resonant frequency. A finite element formulation with the axial components of the field is used (N. Mabaya, MTT-29, pp.600-605). The external quality factor is calculated expanding the resonator field into transmission line eigenmodes to evaluate the power dissipated in the line.

This method does not require the evaluation of the transmission line characteristic impedance. The procedure can be applied to calculate the coupling between resonators with different shapes (cylindrical, ring, double, etc.) and transmission lines (waveguides, microstrip, fin-line, etc.).

The coupling between a cylindrical dielectric resonator and a fin-line (fig.1) has been calculated with this method and studied as a function of the most relevant parameters of the structure (distance between the fin-line gap and the resonator, location of the resonator, fin-line parameters, etc.). Several experimental measurements have been carried out to test the validity of the method and good agreement with the calculated results was observed.



PHILA. NORTH
B-8—SCATTERING I

Chairman: L. Wilson Pearson
TUESDAY-AM

ANALYSIS OF AN OPEN-ENDED ELLIPTICAL WAVEGUIDE IN A PLANAR STRATIFIED MEDIUM

T.M. Habashy[*], *W.C. Chew*[**], and *J.F. Kiang*[***]

[*] Schlumberger-Doll Research, Old Quarry Rd, Ridgefield, CT 06877-4108
[**] Dept. of Electrical and Computer Engineering, Univ. of Illinois, Urbana, IL 61801
[***] Dept. of Electrical Engineering and Computer Science, MIT, Camb., MA 02139

The radiation of a flanged open-ended elliptical waveguide, which is excited by an arbitrary incident waveguide mode, a point source or a probe, into a planar stratified medium, is investigated analytically. The complexity of analyzing the discontinuity at the waveguide aperature stems from the fact that the electromagnetic field is mainly vector in nature. Also, the necessity of matching the discrete modes inside the waveguide to the continuum radiation modes in the open space makes the bookkeeping process cumbersome. A vector Mathieu transform together with a vector Mathieu series are developed and their properties are discussed, which help facilitate the analysis and simplify the process of matching the boundary conditions at the waveguide aperture.

The vector Mathieu transform is introduced to express the continuous spectrum of radiation modes in the planar stratified medium whereas the vector Mathieu series helps in providing a convenient bookkeeping technique for representing the discrete modal spectrum inside the waveguide. With the help of the orthogonality relationships of these operators, mode matching at the waveguide junction can be carried out in a simple manner and hence allows us to compute the transmission and reflection operators at the plane of discontinuity. These transmission and reflection operators represent the mode conversion physics at the discontinuity.

ON THE EM SCATTERING BY AN OPEN-ENDED DIELECTRIC LOADED RECTANGULAR CAVITY IN A GROUND PLANE

James R. Lyons
Jet Propulsion Lab., Califonia Inst. of Technology
Pasadana, CA. 91109

P.H. Pathak
The Ohio State University
ElectroScience Lab. Department of Electrical Engineering
Columbus, Ohio 43212

Efficient moment method (MM) based approaches are investigated for analyzing the problem of EM plane wave scattering by an open ended, perfectly-conducting , two dimensional dielectric loaded rectangular cavity in a ground plane. An integral equation for the unknown electric field in the aperture at the open end is obtained via the use of special Green's function for the conducting half space and the cavity,respectively.The cavity Green's function is represented by a rapidly convergent expansion in terms of modes propagating parallel to the aperture rather than transverse to it. Next, Galerkin's method is used to obtain the MM equations. For small to moderatly large apertures, the unknown aperture field is represented by a set of conventional waveguide modes as the basis functions. This approach appears to be more efficient than one employing subsectional basis functions, and it works even for near grazing incidence. In the case of backscatter from deep cavities only a few selected modes are necessary for describing the aperture field. For electrically large apertures and cavities which are not too deep, the aperture field is expressed as a hybrid commbination of the known geometrical optics field together with a pair of oppositely traveling surface wave basis functions (if surface waves exist) and a set of basis functions near the aperture edges. Such a hybrid represetaion with just a few unknowns (with the number of unknowns being independent of the aperture size) is far more efficient than using a large number of conventional subsectional basis set in the case of large apertures. Additional ways to analyze this scattering problem will also be discussed, and the accuracy of the results obtained by the above approaches will be indicated by comparison with results based on a conventional MM analysis.

ASYMPTOTIC THEORY OF SCATTERING BY CYLINDERS COMPRISING MULTIPLE LAYERS OF DIFFERENT MATERIALS

L. Wilson Pearson
McDonnell Douglas Research Laboratories
P. O. Box 516
Saint Louis, MO 63166

The angular propagation around a metallic cylinder clad by a single lossless dielectric layer has been studied by a number of researchers, most notably Elliott (J. Appl. Phys., 4, 368-376, 1955), who did the original work on this subject. Recently, computational capability has been developed for the application of Elliott's concepts to multilayered regions, including the effects of non-normal incidence and of material losses (L.W. Pearson, North Am. Radio Sci. Meeting, Vancouver, B.C., June, 1985; L.W. Pearson, National Radio Sci. Meeting, Boulder, CO, Jan., 1986). The multilayer formulation can be put into a ray-optical format so that coated cylinders can be incorporated into the collection of GTD (geometrical theory of diffraction) canonical shapes.

The most notable complication introduced by the presence of the dielectric layers occurs in the illuminated-to-shadow transition region. It is necessary to evaluate numerically the spectral integral over angular wave-numbers in this region. The Bessel functions that appear in the integrand are approximated by their Airy function representations in the course of this numerical integration, and the resulting functions have traditionally been represented variously as Fock functions, Pekeris caret functions, or simply termed transition functions (c.f. P.H. Pathak, Radio Sci., 14, 419-435, 1979). For impedance-surface cylinders these functions have been extensively tabulated in a Lockheed report by Logan and Yee (1959).

In this presentation, it is shown that the transition region integrals for the penetrable case can be expressed in a form identical to that of the surface impedance case, but in which the formerly constant impedance function becomes dependent on the variable of integration. Because dissimilar materials are present, Bessel functions of different arguments appear in this function, and recourse to the uniform asymptotic representations of Bessel functions is required. (In previous transition function developments, only a single number appears in the argument of the various Bessel functions present.) These representations are a little more complicated than the simpler Airy function representations, however, so that the complexity of the integrand increases principally through the number of different materials present and its numerical integration seems well within the scope of present-day computers. The analysis leading to the foregoing statements is presented, and observations about its computability are made.

SCATTERING FROM A PERFECTLY CONDUCTING, FINITE, OPEN CYLINDER COATED WITH A THIN, HOMOGENEOUS DIELECTRIC LAYER

P. L. Huddleston
McDonnell Douglas Research Laboratories
P.O. Box 516
St. Louis, Missouri 63166

A formulation of electromagnetic scattering from coated cylinders is developed for the case of an infinitesimally thin, perfectly conducting, circular cylinder coated with a thin uniform layer of dielectric material. The surface equivalence principle is applied to obtain a system of integral equations relating the unknown equivalent surface currents. The layer, which may coat the inner or outer surface of the conductor, is assumed to be thin enough that surface currents on the ends of the layer can be neglected. The method of moments with entire domain expansion and testing functions is used to solve the system of integral equations numerically. Results of calculations for various cylinder aspect ratios, layer thicknesses, and coating constitutive properties are presented. The computational results are compared with experimental data.

NUMERICAL SOLUTION OF ELECTROMAGNETIC SCATTERING PROBLEMS INVOLVING HOMOGENEOUS DIELECTRIC BODIES VIA A SINGLE INTEGRAL EQUATION

Allen W. Glisson
Department of Electrical Engineering
University of Mississippi
University, MS 38677

Beshara I. Sholy
Avionics Engineering Technology
Parks College
Cahokia, IL 62206

Electromagnetic scattering problems involving homogeneous dielectric bodies can be modeled using a single surface integral equation formulation, as opposed to the usual coupled surface integral equation method. In the single integral equation formulation, the number of unknowns required to model the dielectric scatterer is reduced by analytically eliminating one of the equivalent surface currents, either the electric current $\underline{J}$ or the magnetic current $\underline{M}$, at the dielectric body surface. The resulting integral equation can be solved for the remaining equivalent surface current. This surface current may then be used to compute the scattered field via radiation in a homogeneous medium. Additional computations would be required if it is desired to compute the field interior to the scatterer surface.

In this paper a relatively simple numerical implementation for the solution of scattering by homogeneous dielectric bodies via the single integral equation approach is considered. The numerical procedure is developed in such a way that portions of existing algorithms for perfectly conducting scatterers may be easily combined to yield the program for dielectric scatterers. Advantages and disadvantages of the approach are discussed. The procedure is applied for cases involving two-dimensional geometries and for both TE and TM illuminations. Results are presented for computed surface current density and radar cross section for cylinders having various dielectric constants. Data obtained with the method are also compared with results obtained via other applicable methods.

ELECTROMAGNETIC SCATTERING FROM A DIELECTRIC BODY USING PHYSICAL OPTICS

D.J. JANSE VAN RENSBURG, J.A.G. MALHERBE and D.A. McNAMARA

Department of Electronic Engineering,
University of Pretoria, Pretoria, South Africa

Exact methods are not usually suitable for finding the scattering from hollow dielectric scatterers of practical interest. One approximate technique uses the volume equivalence principle current $J = j\omega E(\varepsilon - \varepsilon_0)$ by assuming E to be the incident field (a Kirchoff type approximation). However, this requires that a volume integral be performed, which besides being time-consuming, is not easily incorporated into existing physical optics codes for conducting scatterers, which deal only with surface integrals. A surface current formulation is preferred even for dielectric scatterers.

This paper describes a direct method of calculating the electromagnetic backscatter from a complex hollow dielectric body. Electric and magnetic surface equivalence currents are defined on the surface of the dielectric body and the scattered far fields calculated from the appropriate vector potentials. The fields on the surface of the dielectric body are obtained by making use of the directional impedances (and the reflection coefficients calculated therefrom) for infinately large planar dielectric slabs.

For a smooth shaped dielectric body with a thickness much smaller than the radius of curvature of the surface, the assumption is made that at each point on the surface the equivalence currents can be found from the reflection coefficients of the planar slab of equivalent thickness at that point, taking into account the correct angle of incidence. These currents are then integrated over the illuminated portion of the scattering surface to find the required scattered fields.

The theory presented differs from conventional physical optics in that the reflection coefficients contained inside the radiation integral are functions of both angular variables.

Comparisons between computed and measured results for simple shapes (e.g. finite dielectric plates, dielectric half-cylindrical shell) will be presented.

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HIGH FREQUENCY SCATTERING FROM A COATED CYLINDER IN WHICH THE RELATIVE PERMITTIVITY OF THE COATING IS LESS THAN UNITY

John M. Dunn
Division 7553
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185

In this talk we examine the problem of high frequency scattering from an infinite cylinder which is coated with a dielectric. The relative permittivity of the dielectric is less than that of the surrounding medium. The problem is chosen as a prototype for the study of scattering from objects with a multiple number of layers, the permittivity of which may be chosen in such a way as to allow layers with higher relative permittivities to be placed over those with lower ones. It is found that there are two contributions to the fields. The first contribution is from the local scattering of the incident wave by the cylinder in a manner essentially the same as geometrical optics. The magnitude of the scattering can be well approximated by the use of an impedance boundary condition. The second contribution comes from a wave which travels through the dielectric layer. This wave is approximated in one of two ways. For points on the surface which lie well within the illuminated region, the field is found by first calculating the field resulting from scattering by a magnetic conductor, and then using this field as a boundary condition to calculate the fields in the dielectric region. This procedure allows the media to be separated from one another. For points well within the shadow region, the wave can be approximated as coming from a magnetic dipole placed in the center of the illuminated region. The strength of this dipole is found by integrating the electric field found from the magnetic conductor approximation over the surface of the cylinder. The results are seen to agree well with the exact solution available for the problem. Hopefully, it will be possible to generalize the procedure to objects whose geometries do not allow an explicit analytical solution, although this work is not carried out here.

ELECTROMAGNETIC SCATTERING BY TWO PARALLEL DIELECTRIC PROLATE SPHEROIDS

B.P. Sinha and M.F.R. Cooray
Faculty of Engineering and Applied Science
Memorial University of Newfoundland
St. John's, NF, Canada A1B 3X5

The multipole expansion technique applied by the authors (January 13-16, 1986 URSI Meeting, Boulder, Colorado) to the scattering from a single dielectric prolate spheroid of refractive index n_2 embedded in an infinite homogeneous and isotropic dielectric medium of refractive index n_1 propagating the incident plane electromagnetic wave with arbitrary polarization and angle of incidence employing $\vec{M}^{(a)}$ vectors for E-field expansion and $\vec{N}^{(a)}$ vectors for H-field expansion [$\vec{M}^{(a)} = \vec{\nabla}\,\phi(h;\xi,\eta,\phi) \times \hat{a}$, $\hat{a} = (\hat{x},\hat{y},\hat{z})$; $\vec{N}^{(a)} = \frac{1}{k}\,\vec{\nabla} \times \vec{M}^{(a)}$] has been used in the present problem together with the translational addition theorems for spheroidal vector wave functions (B.P. Sinha and R.H. MacPhie, Quart. Appl. Math., 38, 143-158, 1980). The translational addition theorems which transform the outgoing wave from one spheroid into the incoming wave at the other spheroid assume the simplest form for $\vec{M}^{(a)}$ and $\vec{N}^{(a)}$ vectors because they translate like a scalar wave function $\phi(h;\xi,\eta,\phi)$ (B.P. Sinha and R.H. MacPhie, IEEE Trans. AP, 31, 294-304, 1983). The interacting spheroids are assumed to be composed of the same dielectric material.

The general solution for a N-body system of dielectric prolate spheroids is obtained in the form $\underline{S} = [G]\,\underline{I}$, where $\underline{S}$ and $\underline{I}$ are respectively the column vectors of the coefficients of the series expansions of the scattered and transmitted fields taken together and the incident field. [G] is the transformation matrix which depends only upon the geometries and spacing of the scatterers. Numerical results in the form of curves of scattering cross-sections are given for varieties of two body systems of parallel dielectric prolate spheroids.

DIPOLE-AT-A-COMPLEX-POINT APPROXIMATION OF SMALL AND MEDIUM SIZED SOURCES AND DIELECTRIC SCATTERERS.

Ismo V. Lindell, Keijo Nikoskinen
Helsinki University of Technology, Electromagnetics Laboratory
Otakaari 5A, SF-02150 Espoo 15, FINLAND

Classical multipole theory valid for radiation from sources with small dimensions is extended to multipoles with source points in complex space.

It is shown that, in general, the approximation by an electric dipole or a combination of an electric and a magnetic dipole is improved if their location is chosen in a suitable manner, instead of taking the origin or some geometrically obvious point. The optimal point will in general be in complex space. An expression for the complex location is derived which minimizes the effect of the second-order multipole so that the first-order multipole will be most dominating. From a simple example, radiation from a cubic source with a propagating current wave, it is seen that the radiation characteristic will be an order of magnitude in L/λ better for the dipole approximation when the dipole is the optimal complex point instead of being at the center of the cube. Simultaneously, it is demonstrated that the validity of the dipole approximation is extended from $L \ll \lambda$ to about $L < \lambda/2$, L being the measure of the source.

Complex locations for the approximating electric dipoles of dielectric spherical or spheroidal scatterers are found through integral equation analysis for a propagating incident wave. Other incident waves and generalizations of the theory are also discussed. Some numerical data are presented to find limits of applicability for the present dipole-at-a-complex-point approximation.

SALON 3/4
B-9—INVERSE SCATTERING II (MULTIDIMENSIONAL IMAGING)

Chairman: W.M. Boerner
TUESDAY-AM

MICROWAVE DIVERSITY IMAGING WITH NEAR OPTICAL RESOLUTION

N.H. Farhat, T.H. Chu*, C.L. Werner†, and Y. Shen
University of Pennsylvania
The Moore School of Electrical Engineering
Electro-Optics and Microwave-Optics Laboratory
Philadelphia, PA 19104

Abstract

The principles and methodologies of 3-D microwave and millimeter wave tomographic imaging utilizing spectral, polarization, and angular (aspect dependent) diversity or degrees of freedom are presented. The crucial roles of (a) a novel *target derived reference technique* based on *sinogram pattern* representation of the scattering centers of the target and (b) of the projection-slice theorem in efficient and cost-effective data acquisition and processing are ellucidated. Results of applying the concepts described to realistic data collected in our *Experimental Microwave Measurement and Imaging Facility* (Fig. 1) for a variety of reflecting and penetrable test objects including scale models of aero-space targets and simple dielectric bodies will be given. Image reconstruction algorithms utilizing *Fourier Inversion* and *filtered-back projection* based on equivalent temporal impulse response consideration are described and their equivalence demonstrated. The results, an example of which is shown in Fig. 2, indicate in agreement with theoretical estimates of image information content that high resolution speckle-free, *projection images* of 3-D distributions of scattering centers on distant targets can be formed with near optical resolution (or even better when we consider the severe limitation on resolution of optical systems imposed by atmospheric turbulence). Finally the implications of this work in inverse SAR, collectively operated imaging radar networks, nondestructive evaluation, and radar cross-section measurement, are discussed.

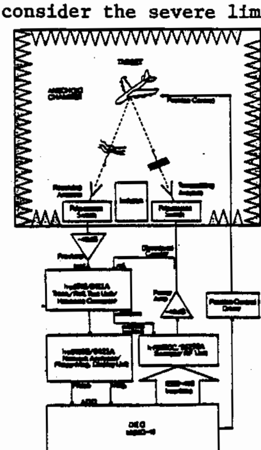
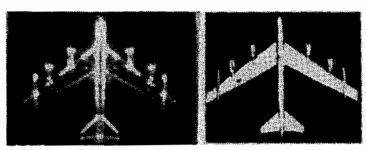


Fig. 1. Imaging facility.



(a) (b)

Fig. 2. (a) Projection image of a metalized 100:1 scale model of a B-52. Spectral range (6-17) GHz. Angular window 90°. Elevation angle 30°. (b) Optical image.

* Presently with the RCA D. Sarnoff Research Center, Princeton, NJ 08540
† On leave from JPL, Pasadena, CA 91109

A HIGH FREQUENCY INVERSE SCATTERING MODEL FOR SMOOTH, CONVEX, CONDUCTING SCATTERERS IN THE SLIGHTLY BISTATIC CASE

Bing-Yuen Foo and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Engineering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

and

Sujeet K. Chaudhuri
Department of Electrical Engineering
University of Waterloo
Waterloo, Ontario, N2L 3G1 Canada

ABSTRACT

Theories of physical optics far-field inverse scattering have been developed and applied to target imaging with varying degrees of success by many researchers for the monostatic case. In this work, an early time expression for the impulse response of a smooth, convex, conducting target is derived under the physical optics assumption in the slightly bistatic case. The expression is found to be an extension of the Kennaugh-Cosgriff formula for the monostatic case (Kennaugh and Cosgriff, IRE Nat'l Conv. Rec., Part, I, 1958), and also in the bistatic case, it is proportional to the second derivative of some silhouette area function of the target. However, under the PO assumption, the early time expression does not manifest depolarization effects. Certain polarization corrections to the PO formulation can be accomplished in the bistatic case by extending Bennett's polarization correction in the monostatic case through his space-time integral equation approach and his leading edge assumptions. By incorporating such a bistatic polarization correction into the early time physical optics impulse response, and Fourier-transforming to the frequency domain, a high frequency inverse scattering model is obtained.

Recovery of geometrical information about the specular region of the target such as specular curvatures, target orientation and cross-sectional area functions can be made possible with the use of our results from the knowledge of the bistatic polarimetric data. For target profile recovery, braodband polarimetric measurements are required for all aspects, as in the backscattering case (Boerner, Ho & Foo, IEEE Trans. AP-S, Special Issue, March 1981). It is found that polarization correction of Kennaugh's ramp response concept and Radon's concept of shape reconstruction from cross-sectional areas can be combined and applied to bistatic radar target imaging which should result in a useful tool for bistatic radar target interrogation.

ACCURATE RECONSTRUCTION OF TWO-DIMENSIONAL CONVEX CONDUCTING TARGET SHAPES FROM A SINGLE-POINT TM SCATTERED FIELD PULSE RESPONSE

Mark Strickel and Allen Taflove
EECS Department, Northwestern University
Evanston, IL 60201

Korada Umashankar
EECS Department, University of Illinois at Chicago
Chicago, IL 60680

This paper reports the use of the finite-difference time-domain (FD-TD) method to accurately reconstruct the shape of two-dimensional convex conducting targets from a single-point TM scattered field pulse response. The general approach involves setting up a numerical feedback loop which uses a 2-D FD-TD code as a forward-scattering element, and a nonlinear optimization code as the feedback element. FD-TD generates a test pulse response for a proposed target shape. The test pulse is compared to a measured pulse, and an error signal is developed. Working on this error signal, the nonlinear optimization element perturbs the originally proposed target shape in a manner to drive down the error. Upon repeated iterations, the proposed target shape ideally converges to the actual shape.

The advantage of working in the time domain is that a target shape can be reconstructed sequentially in time as the incident pulse moves across the target, taking advantage of causality. This reduces the complexity of reconstruction since only a portion of the target shape is being generated at each iteration.

Detailed target reconstruction begins by locating the point on the scatterer that is first illuminated by the incident pulse. The lattice points adjacent to the initial point are then perturbed by sequentially assigning them high values of conductivity. The new addition to the target surface is obtained by comparing the scattered electric field values (observed at a single point) for each perturbation with the measured values, and selecting the surface perturbation that gives the best agreement with measured data in the least-squares sense. This process is repeated using the target surface points generated in the previous iteration as the base from which to launch the new surface perturbation. In this manner, the actual target surface contour is generated synchronously as the leading edge of the incident pulse moves across the target.

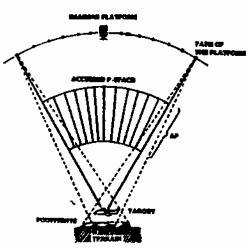
This technique has been successfully used to accurately reconstruct simple convex target shapes such as triangles and rectangles. Currently, the "measured" input data is generated by a very high resolution forward FD-TD code for a half-sine incident pulse, and reconstruction is accomplished with a coarser resolution FD-TD code. Efforts are now underway to obtain actual measured data for such 2-D targets. Preliminary indications are that measurement errors may primarily affect reconstruction of the target shape in shadow regions.

MICROWAVE DIVERSITY IMAGING OF OBJECTS IN THE PRESENCE OF SEVERE CLUTTER

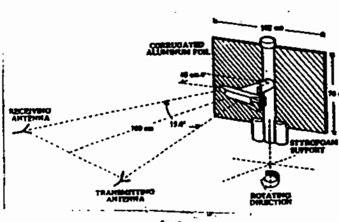
Nabil H. Farhat and Yuhsyen Shen
University of Pennsylvania
The Moore School of Electrical Engineering
Electro-Optics and Microwave-Optics Laboratory
Philadelphia, PA 19104

Abstract

Frequently microwave imaging situations arise where the object being imaged is situated against a strongly reflecting background that produces severe clutter or is obstructed by clutter producing foreground or interface. Examples are found in air-borne or space-borne down-looking imaging radars and systems for the imaging of internal structure of penetrable bodies. The aim of this paper is to demonstrate the capability of a high resolution microwave diversity imaging system in discriminating objects of interest in the presence of such severe clutter. The approach is based on a *spot-light imaging mode* in which spectral, angular, and polarization diversities are utilized to access the three-dimensional Fourier space of a coherently illuminated microwave scene. A brief theoretical review of the principle is presented followed by a description of the microwave imaging configuration (Fig. 1b) employed in collecting realistic data of a representative situation: that of a low flying aircraft depicted in Fig. 1a. The antennas in Fig. 1b are positioned as if they were space-borne looking downward towards the target and the ground. Only one two-dimensional slice of the three-dimensional Fourier space is obtained; hence the reconstructed image obtained by Fourier inversion is a projective side-view. The reconstructed images show clearly the ability to differentiate the object image from the background clutter simulated in our experiments by ground planes overlayed by crumbled aluminum foil. The polarization-enhanced microwave images obtained are comparable visually to high contrast side-view photographs of the scene taken with flood light illumination (Fig. 1c). Finally the effect of relative motion and how to account for it in the measurement is discussed.



(a)



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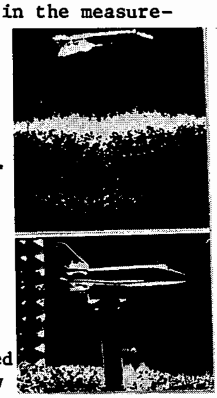


(c)

Fig. 1. (a) simulated imaging geometry, (b) experimental imaging arrangement, (c) polarization enhanced projective image (top) and equivalent pictorial view of the target (bottom).

RADAR CROSS-SECTION MANAGEMENT STUDIES EMPLOYING MICROWAVE DIVERSITY IMAGING

Nabil H. Farhat, Hsueh-Jyh Li and Yuhsyen Shen
University of Pennsylvania
The Moore School of Electrical Engineering
Electro-Optics and Microwave-Optics Laboratory
Philadelphia, PA 19104

Abstract

Microwave diversity imaging systems using spectral, angular and polarization diversities have the capability to obtain an image with near optical resolutions. One of its applications is in radar cross-section (RCS) management where the hot spots (distribution of scattering centers) of targets are determined over prescribed spectral and angular windows. In radar cross-section management it is sometimes desired to reduce the RCS of an object. One possible method is to cover the hot spots with absorbers or coating material. The aim of this paper is to experimentally demonstrate the utility of microwave diversity imaging in RCS management. An image of a test object, a metalized scale model of a B-52 aircraft is obtained first to identify the hot spots, some of these (parts of the edges, engines) are then covered with broadband absorbers and the imaging operation repeated. The reconstructed image of the "diaphonized" object shows the brightness of those parts covered with absorbers has been reduced (Fig. 1). This provides a measure of the effectiveness of the coating. The scattered fields (frequency response) and their Fourier transform, yielding the range-profile of the object, before and after insertion of the absorber are shown in Fig. 2 for a broad-side view. From these plots, the effect of the absorber on the RCS and the visibility of the reconstructed image can be quantitatively determined. Examples showing the effect of the insertion of absorbers on the edge diffractions and on the reduction of RCS as well as the brightness of the reconstructed images will be presented and discussed.

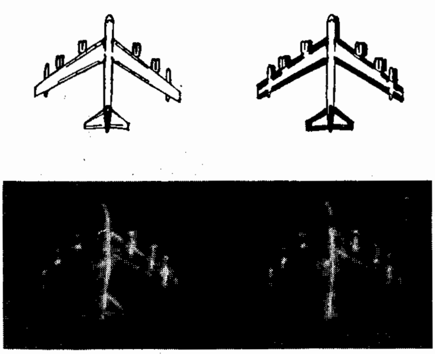


Fig. 1. Sketch of the test target (top, with dark areas showing the covered portion) and the reconstructed images (bottom) before (left) and after (right) diaphonization.

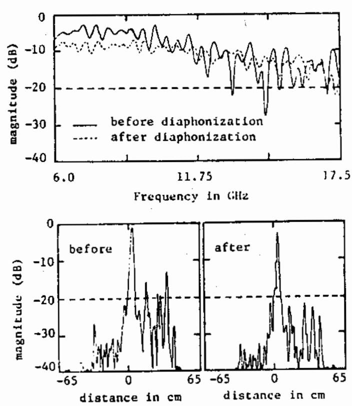


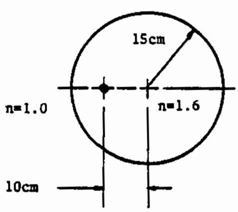
Fig. 2. Frequency response (top) and corresponding range profile (bottom) before and after diaphonization.

MICROWAVE DIFFRACTION IMAGING OF A POINT SOURCE IN A DIELECTRIC

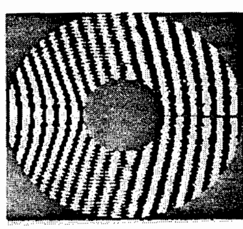
Kenneth Schultz and Dwight L. Jaggard
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Imaging of dielectric objects with microwave radiation has received considerable attention in recent years. Such imaging systems have, in general, obtained reasonable reconstructions for the restricted class of semi- transparent low-loss scatterers. Most materials, however, violate such conditions and pose a problem for existing diffraction based imaging systems. In particular, the effects of refraction and multiple scattering cause severe artifacts in images obtained using standard reconstruction techniques. The purpose of this presentation is to discuss a class of scatterers which facilitate the study of the effects of both refraction and multiple scattering in images obtained using reconstruction schemes based on the Born approximation. Specifically, Born reconstructions are obtained for the case of a line source located within a (lossless) dielectric cylinder.

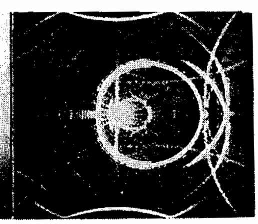
Images are generated using both simulated and experimental data sets. Simulated data is computed using the analytic expression for the Green's function of a circular dielectric cylinder. Knowledge of the analytic form of the Green's function allows computation of simulated field measurements without resort to time consuming iterative or moment method techniques. In both simulated and experimental data sets, far-field, multi-aspect, scattering measurements are used as raw data. Preliminary results using simulated data are shown below. Figure (a) presents the geometry of the experiment, figure (b) shows the real part of the acquired (range corrected) data, while figure (c) shows the Born reconstruction. Each radially directed line segment in figure (b) represents a 6-17 GHz slice of data for a single view. Image artifacts due to the relatively high index of refraction are clearly visible in figure (c).



(a)



(b)



(c)

VECTOR DIFFRACTION TOMOGRAPHY
in
COMPUTER ASSISTED ELECTROMAGNETIC IMAGING

Brian D. James and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Engineering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

ABSTRACT

This research deals with the image reconstruction problem using inverse methods for the electromagnetic vector diffraction problem. Using a so-called Fourier-weighted Radon transform, we are able to develop an expression for the relative index of refraction which closely resembles existing expressions for the scalar diffraction problems in acoustic and microwave tomography. Further, we develop an extended modified-filtered-backprojection algorithm and an extended filtered-backpropagation algorithm, both resembling the existing algorithms used in scalar diffraction tomography.

Whether the index of refraction is described in complete tensorial form (for anisotropic media) or in scalar form (for isotropic media), vector diffraction may dominate in certain situations and, therefore, is of considerable importance for high-quality image reconstruction. Particularly, vector diffraction effects are often noticeable within objects containing sharp discontinuities between homogeneous regions with diameter comparable to the wavelength of the illuminating source.

This research offers a new tensorial reconstruction technique based on existing tomographic methods which make use of Radon transform theory. Green's dyadic functions $\bar{\bar{G}}(\bar{x},\bar{y}) = (\bar{\bar{\sigma}} + \{1/k^2\}\overline{\nabla\nabla}_x)\exp(jk|\bar{x}-\bar{y}|)/|\bar{x}-\bar{y}|$ are used to describe the vector diffraction problem of an incident field $\bar{\phi}(\bar{y})$ scattered within an arbitrary medium, described by its relative index of refraction $\delta n(y)$, to yield an exterior field $\bar{\psi}(\bar{x}) = \bar{\phi}(\bar{x}) + \int d\bar{y}\, \bar{\bar{G}}(\bar{x},\bar{y}) \cdot \left[\delta\bar{\bar{n}}(\bar{y}) \cdot \bar{\phi}(\bar{y})\right]$. To parallel the existing work in scalar diffraction tomography, we assume the validity of the first-order diffraction approximation, the Born approximation, and stationary, band-limited characteristics.

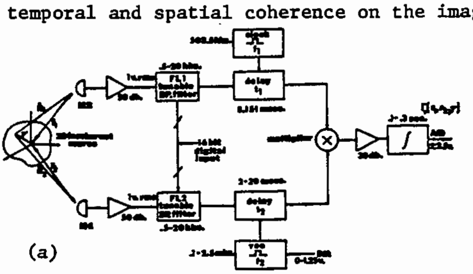
The vector reconstruction expression developed here is numerically implemented using an extended modified-filtered-backprojection algorithm, and the effects of neglecting vector diffraction (particularly within isotropic media) is briefly studied. The results of these numerical experiments show that neglecting vector diffraction in image reconstruction may yield poor results.

TOMOGRAPHIC IMAGING OF 3-D INCOHERENT OBJECTS EMPLOYING SPECTRALLY SELECTIVE CORRELATION MEASUREMENTS

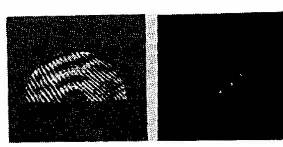
C.L. Werner and N.H. Farhat
University of Pennsylvania
The Moore School of Electrical Engineering
Electro-Optics and Microwave-Optics Laboratory
Philadelphia, PA 19104

Abstract

We show that the basic concepts of broadband coherent 3-D imaging by wave-vector diversity [N. Farhat et. al., J. Radio Science, 19, 1347, 1984] are extendable to projection and tomographic imaging of 3-D incoherently emitting bodies. The extension is based on duality of the propagation and scattering behavior of the complex field amplitude and the mutual coherence function. Two equivalent methods for accessing the 3-D Fourier space of an incoherently emitting body are described. One is based on spectrally selective cross-correlation measurements of the random wavefield produced by the object as a function of object aspect (see Fig. 1). The other is based on measuring the cross-spectral power density as function of aspect angle. Once a volume of the object's 3-D Fourier space is accessed, tomographic or projective images of its 3-D intensity or brightness distribution are reconstructed based on the projection-slice theorem. Verification of the above concepts is important for true 3-D passive imaging (3-D radiometry, thermography and noise analysis in machinery) and has implications in remote sensing, surveillance, and emitter identification. The results of a verifying experiment using the acoustic implementation of Fig. 1a will be described for a discrete 3-D object consisting of three acoustic tweeters excited by incoherent noise sources. Typical correlogram (Fourier space slice) and projection image obtained by Fourier inversion are shown in Fig. 1c. Tomographic images (slices) through the object obtained by application of the weighted projection slice theorem to the 3-D Fourier space data will also be presented and the effect of the object's temporal and spatial coherence on the image will be described.



(a)



(b) (c)

Fig. 1. (a) Measurement system, (b) correlogram of the object obtained with spectral window of (1.9-9.9)kHz and angular window of 180°, (c) projection image obtained by Fourier inversion.

* On leave from JPL, Pasadena, CA. 91109

A SURVEY OF IMAGE-EMBEDDED PASSIVE BEAMFORMING SOURCES FOR A RADIO CAMERA

J. Halat and B.D. Steinberg
Valley Forge Research Center
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

An array that affords no accurate a priori element position information, as is the case for a radio camera in general, demands some form of adaptive processing in order to function as a diffraction-limited imaging system. Adaptive beamforming is a technique that exploits the well behaved amplitude and phase properties of a single point target or source.

Echoes from the object field which exhibit radiation properties similar to those of a point source can be used as beamforming sources. A survey has been performed on the availability and detectability of passive beamforming sources embedded in the object field of a radio camera system. Industrial, residential and undeveloped scenes provided the data for the survey.

A variance measure was applied to the echo amplitude data of the random array for beamformer detection and a correlation measure of image quality was included to analytically define acceptable beamforming sources relative to known standard beamformers.

Between 2.7% and 16.9% of the range bins studied, depending on the scene type, behave as good beamforming sources. Of these, 1.8% to 5.8% are detected by the variance test. Since radar systems typically operate with 1000 range bins, an abundance of detectable scatterers capable of cohering the array is available.

PHILA. NORTH
B-10—SCATTERING II
Chairman: L.N. Medgyesi-Mitschang
TUESDAY-PM

SCATTERING FROM A CORRUGATED RESISTIVE SHEET

R.C. Hall and Raj Mittra
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

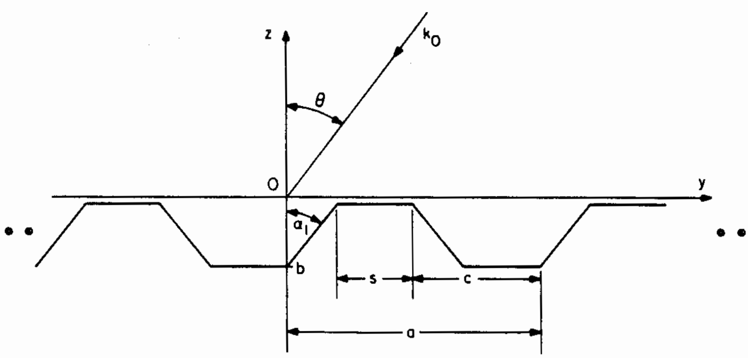
Thin resistive sheets that satisfy the so-called resistive or jump boundary condition have applications in RCS reduction work. This boundary condition relates the tangential electric fields on a thin sheet to the induced current and may also be applied to certain thin metalic structures where loss is unavoidable. More explicitly, the boundary condition can be written

$$E_{tan}^{+} = E_{tan}^{-} = R_0 J = E_{tan}^{inc} + E_{tan}^{scat} \tag{1}$$

where J is the induced current on the sheet due to a given incident field E_{tan}^{inc}, R_0 is the resistance of the sheet in ohms/square and E_{tan}^{+} and E_{tan}^{-} are the tangental electric fields on the top and bottom faces. This boundary condition should not be confused with the impedance (or Leontovich) boundary condition though the two are not unrelated.

The reflection and transmission coefficients of a planar sheet of resistive material are easily calculated. However, when the material is corrugated as in Figure 1 the scattering properties are more complex. This structure is infinitely periodic in y and invariant in x. In this paper it is shown how the Spectral-Galekin numerical technique may be used to analyze structures of this type when the incident field lies in the $\hat{x}-\hat{z}$ plane, transverse to the corrugation. The Spectral-Galerkin technique works in the transform domain where the convolution form of the integral equation for the scattered field reduces to product form. The integral equation is of the second kind when the resistive boundary condition is applied. The induced currents are determined via a procedure similar to the method of moments. A technique to extend the Spectral-Galerkin method to the very low frequency region is also described.

Reflection and transmission coefficients are presented for the structure shown in Figure 1 over a wide frequency range.



WAVE SCATTERING BY A SINUSOIDAL SURFACE: A VARIATIONAL APPROACH

Ernest P. Gray and Joseph F. Bird
Applied Physics Laboratory
The Johns Hopkins University
Johns Hopkins Road
Laurel, Maryland 20707

We have used the Schwinger variational method to calculate the field ψ^{sc} scattered by a perfectly conducting sinusoidal surface (whose corrugations run along the y-direction) when irradiated by an incident plane wave ψ^{inc} (propagating in the x-y plane of incidence). The theory of diffraction by periodic surfaces goes back to Rayleigh (1907) and has a rich history. The only previous bona fide variational approach, however, appears in an unpublished report by Lippmann, who used plane-wave trial functions in a Schwinger-type variational principle but did not carry the variational solutions to completion.

The main thrust of the present work is to experiment with trial function selection and to judge the variational results by a numerical comparison with known exact solutions. The most significant contribution we have made here is the recognition that the only a priori requirement for a trial function is that it satisfy the boundary conditions of the problems on the periodic scattering surface $\zeta(x)$; its behavior off that surface is of no importance. We have implemented that requirement for the Dirichlet problem by expressing the scattered trial field in the boundary-Born form, $\psi^{sc}(x,z) = \psi^{inc}(x,z) - \psi^{inc}(x,\zeta(x))f(x,z)$, where $f(x,z)$ must be periodic in x and satisfy the constraint $f(x,\zeta(x)) = 1$, but is otherwise totally arbitrary. We have adopted a particularly simple form for f, $f(x,z) = g(z-\zeta(x))$, with $g(0) = 1$ (an analog of which has previously yielded very accurate variational results for circular cylinder scattering), and have evaluated it variationally, using $\zeta(x) = h \sin Kx$. Our method consists in expanding ψ^{sc} in a Rayleigh expansion and expressing the expansion coefficients in a variationally invariant ratio of surface integrals involving the trial function. The two single integrals in the numerator of that ratio are relatively simple to evaluate. The demoninator, however, a double integral, has resisted all attempts at expressing it in closed form. We have been able to transform it into a double infinite sum of contour integrals whose integrands contain products of two Bessel functions.

Certain limits agree with the exact result. Thus, our variational method is correct in the flat-plane limit ($h \to 0$), the long wavelength limit ($k \to 0$), the short wavelength limit ($k \to \infty$), and Rayleigh's grating limit ($K \to 0$). For other values of these parameters, we have evaluated the variational solution numerically, and compare it with exact results.

SCATTERING CHARACTERISTICS OF A CORRUGATED CONDUCTING CYLINDER

T.C.K. Rao
Electrical Engineering Department, University of Lowell
Lowell, Massachusetts 01854

Abstract

In many applications in radar, it has long been recognized that the introduction of small corrugations on the surface of a conducting cylinder has some beneficial effects in minimizing or maximizing the backscattering crosssection from the cylinder and is considered as an alternative to dielectric coating. Under the assumption that the guide wavelength is much larger than the corrugation constant $D_1 + D_2$ (D_1 = spacing between the discs, D_2 = thickness of the disc), Piefke obtained the solution of the wave equation by considering the inter-disc region as a quasi-homogeneous but anisotropic medium whose dielectric constant and permeability are tensor quantities (G. Piefke, IRE Trans. Ant. and Propagation, S183-S190, Dec. 1959). The scattering characteristics of such a disc loaded Sommerfeld line are investigated when a plane wave is incident on it. In particular, the backscattering crosssection and its variation with the physical parameters of the structure are discussed. The surface impedance concept is critically examined and compared with the results obtained from a numerical solution.

HYBRID SOLUTIONS FOR SCATTERING FROM BODIES WITH SURFACE DISCONTINUITIES

D.-S. Wang
McDonnell Douglas Research Laboratories
P.O. Box 516
St. Louis, Missouri 63166

To properly account for scattering effects resulting from surface discontinuities, an extension of the recently developed hybrid method (L. N. Medgyesi-Mitschang and D.-S. Wang, IEEE Antennas Propagat., Vol. AP-31, No. 4, 570, 1983 and Vol. AP-32, No. 7, 717, 1984) is presented for electromagnetic scattering from electrically large, perfectly conducting and coated bodies. This extension incorporates two features: (a) a mixed boundary condition and (b) a correction to the physical optics (PO) Ansatz. The mixed boundary condition in the integral equation formulation combines the exact boundary conditions for areas near surface discontinuities and the impedance boundary condition (IBC) for the remaining smooth surface. This formulation is then solved using the method of moments (MM) technique with Ansatzes for the surface currents. The correction to the PO Ansatz is similar to the non-uniform current component explicated in the physical theory of diffraction (P. Ia. Ufimtsev, Soviet Physics - Tech. Physics, Vol. 27, No. 8, 1708, 1957). This correction yields greater accuracy than the previous formulation.

The present formulation includes not only higher-order scattering effects resulting from surface discontinuities, but also effects caused by coated surfaces having sharply changing curvatures, such as tips and edges. The formulation preserves the computational advantages of the IBC formulation, substantially reducing the number of unknowns. Representative scattering calculations are performed for axially symmetric bodies to verify the efficacy of the formulation. The results are compared with exact solutions based on the MM technique using exact boundary conditions and with available experimental data for large scatterers.

THE SCATTERING FROM THE OGIVE REVISITED

A. K. Dominek and L. Peters, Jr.
ElectroScience Laboratory
Department of Electrical Engineering
The Ohio State University
1320 Kinnear Road
Columbus, Ohio 43212

The scattered fields of an ogive are revisited from a high resolution radar viewpoint. This particular target has been studied from a number of viewpoints, each yielding some improvement both in the analysis and in the understanding of the scattering mechanisms. First there was the physical optics solution which, of course, was seriously in error. Later the traveling wave concept gave reasonable results for the non-specular return but contributed little to the understanding of the physical scattering mechanisms. Then a modified form of the creeping wave analysis gave better results in the near endfire region, but failed to give adequate performance when the observation point was not in a plane tangent to the ogive surface.

Using both computed results from a body of revolution moment method solution and experimental results in conjunction with high resolution scattering techniques, all of the scattering mechanisms on this shape can be evaluated. The results show that there is the usual creeping wave-tip-creeping wave term for near axial incidence. As the incidence angle increases, this term no longer exists. Here, the dominant term is the direct diffraction from the rear tip with smaller diffraction contributions from the front tip and the tip-creeping wave-tip mechanisms.

We shall present data on the angle of incidence and the frequency dependence of each mechanism as obtained from this high resolution process.

FORMULATION AND NUMERICAL SOLUTION FOR SCATTERING AND RADIATION BY PATCH MODELS OF DISCRETE BODIES OF REVOLUTION

Donald R. Wilton and Robert M. Sharpe
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 involved in determining the induced current in moment method solutions of such problems. 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 then be obtained on a block-by-block basis, thus reducing both solution time and matrix storage requirements. Occasionally, the desired excitation happens to be one of the symmetrical components, in which case only a single block needs to be solved.

In a recent upgrading of capabilities of a surface patch code utilizing triangular patches, both electric and magnetic ground planes (reflection) symmetries in up to three mutually perpendicular planes were treated. In this paper, we examine a common type of rotational symmetry in which the geometrical surface may be rotated about an axis through an angle of $2\pi/N$ into coincidence with itself. We use the term *discrete body of revolution* (DBOR) to describe such a surface, which, for N sufficiently large, can be used to model a continuous body of revolution (BOR). For a BOR, the symmetrical components are the Fourier components of the azimuthal field or current variation; for a DBOR, they are the discrete Fourier transform (DFT) components of these quantities at corresponding symmetrical positions. 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 columns of the original moment matrix. For large N, this may be efficiently computed via the FFT. 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.

It is emphasized that no approximations are introduced in making use of DBOR symmetry and that the analysis can also be effectively used when only a portion of the structure is a DBOR. Furthermore, all the advantages of subsectional modeling are retained. In particular, it appears that the modeling of BOR's with unsymmetrical objects such as fins or wires attached is simplified since one does not require basis functions which provide a transition between the BOR's entire domain and the attached object's subsectional basis functions. Indeed, it appears that there may be generally little advantage to using BOR analysis over DBOR analysis.

SCATTERING FROM A SLIT CYLINDER ENCLOSING AN OFF-SET IMPEDANCE CYLINDER

Richard W. Ziolkowski and Ronald F. Schmucker
Lawrence Livermore National Laboratory
Engineering Research Division
P.O. Box 5504, L-156
Livermore, CA 94550

Canonical electromagnetic aperture coupling problems are important from several points of view. They provide a basic understanding of the coupling process which can be extrapolated to more general geometries. Moreover, they provide fundamental benchmarks for general purpose scattering codes.

The generalized dual series solution to the coupling of an H-polarized plane wave to a perfectly conducting infinite cylinder with an infinite axial slot enclosing an *off-set interior* impedance cylinder has been constructed by Ziolkowski and Schmucker [Boulder USRI Meeting, Jan. 1986]. This is a very important canonical problem because it allows one to study the effects of the location and size of an interior object on the aperture coupling. As one might expect, the off-set interior cylinder breaks the symmetry of the configuration and leads to new effects.

Results will be presented for the case where the interior object is a perfectly conducting wire. Frequency scans of the bistatic cross-section will be given for various locations and radii of the interior wire as well as for different angles of incidence and aperture sizes. These results are dominated by resonance features whose characteristics reflect the variations in those parameters. Plots of the fields, total currents on the slit and interior cylinders, and currents on the inside and the outside of the slit cylinder will also be given at frequencies corresponding to the locations of those resonance features.

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

NUMERICAL ASPECTS OF THE EVALUATION OF HANKEL FUNCTIONS OF COMPLEX ORDER AND ARGUMENT ARISING IN SCATTERING AND DIFFRACTION THEORY

Rick A. Whitaker
McDonnell Douglas Aerospace Information Services
L. Wilson Pearson
McDonnell Douglas Research Laboratories
P. O. Box 516
Saint Louis, MO 63166

When Green's functions for wave equations are represented by the so-called angular propagation representation (or equivalently when the Watson transform is performed on an angularly periodic expansion), the need arises to compute solutions of Bessel's differential equation for complex order, and, potentially, for complex argument. Three-term recursion algorithms are viable for this computation provided the argument and order are not too large in magnitude (say 10). When the magnitude of the order parameter is larger, the functions are exponentially dependent on order so that recursive techniques either become costly or fail entirely because of the influence of limited machine precision. There are three well-documented asymptotic expansions available for solutions to Bessel's equation: the Debye expansions, which are described in detail by Watson (Theory of Bessel Functions, 1966); the transition region expansions due to Olver (Proc. Camb. Phil. Soc., 48, 414, 1952); and the uniform expansions (see F.W.J. Olver, Asymptotics and Special Functions, 1974). The Debye expansions are complicated to apply because the representations change according to the relative location of order and argument in the complex plane and because they fail entirely at the turning point, where argument and order are equal. Olver's expansions are complicated because they depend on the computation of Airy functions of complex argument. The implementation of the uniform expansion is more complicated than the transition region expansion principally because of the polynomial series arising in the expansion.

This presentation reviews the computational issues associated with the approaches enumerated above. The non-trivial problem of validating the calculations of the functions is addressed through numerical comparison of independent methods and through testing the satisfaction of recursion relations that are independent of any algorithmic recursion that is applied. Some observations are made about error estimation and the *a priori* specification of error tolerance.

NATURAL FREQUENCIES OF DIELECTRIC COATED WIRES

Min-Chin Lin and Yean-Woei Kiang
Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan, R.O.C.

ABSTRACT

The natural frequencies of dielectric coated thin wires are numerically computed using a moment method of reaction formulation. Considerable variations of natural frequencies are found under the changes of dielectric constant of the coating. The effects of partial coating are also examined.

INTRODUCTION

Several methods for solving transient scattering problems have been developed during the past decade [1]. One important approach is the singularity expansion method (SEM) based on the analysis of the response in the complex frequency s-domain. The fundamental quantities in the SEM method are natural frequencies at which the natural resonant modes exist in the absence of external excitation. It has been shown that the complex resonant frequencies of the scatterer are determined only by the geometry and composition. This essential property of the natural frequencies may serve for target discrimination and indeed various algorithms have been proposed [2],[3]. Therefore, the study of the effects of dielectric coating on the natural frequencies may be important to the radar target discrimination.

In this paper we investigate the variations of natural frequencies due to dielectric coating by an efficient moment method introduced by Richmond and Newman [4]. The dielectric coated thin wires are examined with the restriction that the coating layer is not too thick.

SALON 3/4

B-11—TRANSIENTS AND RESONANCES

Chairman: K.M. Chen

TUESDAY-PM

DIELECTRIC RESONANCES IN PRINTED MICROWAVE COMPLEMENTARY DIPOLE PAIRS USING HIGH-PERMITTIVITY SUBSTRATES

K. G. Schroeder
American Electronic Laboratories, Inc. Lansdale, Pa., 19446

A previous analysis has shown that microstrip radiators covered with dielectric material will experience a change in resonant frequency and a lower resonant resistance. (A.J.M. Soares, et al; IEEE Transactions AP-32, No. 11, November 1984, pp. 1149-1154.) In this paper, the effect on effective element spacing as well as effective element impedance will be investigated experimentally for the case of endfire complementary pairs of flat sheet dipoles printed on a dielectric substrate of high permittivity. While the same effect on resonant length, effective spacing and patterns is experienced, the impedance can be matched similar to free-space pair, because the external matching mechanism is independent of the substrate permittivity.

EXTRACTION OF THE NATURAL FEQUENCIES OF A COMPLEX RADAR TARGET FROM MEASUREMENTS OF ITS RESPONSE

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

The use of natural resonances in various radar target identification schemes has prompted renewed investigation into methods for the extraction of natural resonance frequencies from measured responses. Prony's method has proven inadequate due to its sensitivity to noise and to the number of modes assumed present in the measured response.

Three methods which are much less sensitive to noise level and to modal content have been developed: the continuation method, a nonlinear least-squares technique, and two E-pulse related schemes. Each of these methods has been quite successful in extracting complex frequencies from numerical data under a variety of circumstances. Most promising, these techniques have also been successful in extracting natural frequencies from complex radar targets, including scale aircraft models. Numerous results will be presented.

EXTRACTION OF TARGET NATURAL FREQUENCIES FROM MEASURED TRANSIENT SURFACE CHARGE AND CURRENT WAVEFORMS

N. Gharsallah, E.J. Rothwell, D.P. Nyquist and K.M. Chen
Department of Electrical Engineering and Systems Science
Michigan State University
East Lansing, Michigan 48824

The natural resonant frequencies of a radar target provide a unique characterization of the transient electromagnetic response of that target; they consequently provide a basis for target identification and discrimination techniques. Those frequencies are commonly extracted from late-time, far-zone, time-domain scattered field measurements. Natural frequency extraction is critically dependent upon the signal-to-noise ratio of measured responses. Target natural resonance frequencies are shared by both its scattered field and its induced surface charge and current distributions. It is therefore suggested, for laboratory scale-model experiments, that the scattered field method be augmented by mode extraction from measured transient near-field surface charge and current waveforms.

A short monopole probe perpendicular to the target surface responds to the normal component of E-field there, which is proportional to the local surface charge density. Similarly, a semicircular loop probe oriented perpendicular to the target surface responds to the tangential component of H-field normal to the loop, which is proportional to the local surface current density. Both of these probes behave as ideal differentiators when electrically small. They offer two main advantages: 1) their responses are relatively large, providing improved signal-to-noise ratio and 2) the early-time periods of charge and current to which they respond is relatively short, permitting natural mode extraction from earlier measured responses of relatively large amplitude. Probe responses to ns-pulse target illumination are measured using a ps-rise-time sampling and waveform processing oscilloscope.

Natural frequencies are subsequently determined by fitting the measured late-time transient surface charge or current waveforms to a natural-resonance-mode SEM representation of those responses. Extraction is accomplished using algorithms based upon the continuation and other methods, subsequent to use of the FFT to provide an initial estimate of frequency content in the measured data.

Adequacy of the SEM representation and the experimental measurement and mode extraction protocols is first tested for thin-wire cylinder and loop targets (natural frequencies known with confidence from analytical computations), where aspect independence of the resulting natural frequencies is confirmed. Natural frequencies of complex aircraft models are subsequently measured using optimally-located surface probes.

Asymptotic Model-Based Transient Electromagnetic Identification

Donald G. Dudley
Robert R. Weyker

Electromagnetics Laboratory
Department of Electrical and Computer Engineering
University of Arizona
Tucson, AZ 85721, USA

To date, methods in transient electromagnetic identification have been based primarily on a pole-zero (PZ) difference equation model. The input-output data associated with the electromagnetic scattering process is entered into the difference equation whose coefficients are then adjusted, by some strategy, to make the model close to the process in some well-defined mathematical sense. The solution to the difference equation is a complex exponential series whose parameters describe a sequence of resonances associated with the difference equation input-output data. In some cases, it has been possible to relate these data resonances to the body resonances of the electromagnetic scattering object. There have been several cogent criticisms of this method. First, even for perfectly conducting scatterers, the complex exponential series is an incomplete description of the scattered field and must be supplemented by the inverse transform of an entire function of frequency. This entire function is incorrectly modeled by the difference equation model. This difficulty is unfortunate since the entire function often represents the dominant contribution to the transient signal. Second, for time-limited data, the identification of the complex resonances is not unique. Therefore, there are no guarantees that the resonances of the data can be related to the body resonances of the scattering object.

It has been shown that for a perfectly conducting scatterer, the entire function contribution is time-limited in the early-time transient response. In this paper, we use this fact to produce an early-time asymptotic identification method. The method is based on the asymptotic expansion of the electromagnetic fields in inverse powers of $i\omega$. This expansion leads to an N^{th} order moving average (MA) difference equation model whose output is the N^{th} backward difference of the scattering process output. We test the method with synthetic data associated with acoustic scattering from a hard sphere. We compare the robustness of the method with results from the more usual PZ model and suggest methods to incorporate the better features of both PZ and MA modeling.

THE EXTRACTION OF SINGULARITY EXPANSION PARAMETERS USING PADE APPROXIMANTS

Donald C. Power
Raytheon Company
Missile Systems Division
Hartwell Road
Bedford, Ma 01730

The extraction of the poles in the Singularity Expansion Method (SEM) using Prony's algorithm is shown to be equivalent to the formation of a particular Pade approximant to the z-transform of the transient response. Although the equivalence of Prony's method to the Pade approximation technique is well known, (L. Weiss and R.N. McDonough, SIAM Review, Vol. 3, 1963), the consideration of the SEM problem from this point of view provides greater understanding and insight. In particular, it is shown that consideration of the singularities of the Pade approximants in the z-plane enables the extraction of information which is difficult to obtain or is undetectable from the standard approach.

GENERATION OF IMPULSIVE WAVEFORMS WITH LARGE ENERGY CONTENT

Tapan K. Sarkar
Department of Electrical Engineering
Syracuse University
Syracuse; New York 13244-1240
(315) 423 - 3775

ABSTRACT : It is highly desirable to obtain impulsive waveforms with a large energy content.This is because for a linear system, an impulse response of the object uniquely characterizes the object just like a finger print identification. This presentation will explore means of generating electrical pulses of about kilovolts in amplitude and about three hundred picoseconds pulse duration. One of the possible applicaions of such a device would be to provide a laboratory tool for the experimental determination of electromagnetic resonances of objects of interest. A second application would in the development of a time domain radar.

K-PULSE ESTIMATION FROM THE IMPULSE RESPONSE OF A TARGET

Fredric Fok, David L. Moffatt and Nan Wang
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus Ohio 43212

A simple and general method is described to estimate the K-pulse of a target from its synthesized or exact impulse response. The approach is based on minimization of energy content outside the K-pulse response duration. The method is simple because it only deals with Dirac delta functions in integrals. It is also general because the method only manipulates samples of a continuous function, a normal computer operation. The method does not require a priori information on the target poles. Results obtained from both exact and synthesized data, show excellent convergence for the K-pulses. Furthermore, dominant poles of the target can be extracted from the approximated K-pulse. The pole-extraction method is also discussed in association with some of the results.

EXTRACTION OF TARGET IMPULSE RESPONSE BY DECONVOLUTION OF REAL-TIME MEASURED DATA

M. Blischke, E. Rothwell, B. Drachman*, D.P. Nyquist and K.M. Chen
Dept. of Elect. Engr. & Sys. Science, Dept. of Mathematics*
Michigan State University, E. Lansing, Michigan 48824

A method of extracting impulse responses of radar targets is being investigated for use as a means of target discrimination in radar.

When a target is illuminated with an electromagnetic impulse, it oscillates electrically at certain natural frequencies characteristic of the target. By measuring these natural frequencies and comparing them various targets can be discriminated. With an ideal TEM impulse and a short monopole acting as an ideal differentiator, the impulse response can be found by integrating the measured response. To improve the signal to noise ratio it is desired to use a long monopole which, however, would cease to approximate an ideal differentiator. A band limited impulse and the frequency characteristics of the transmitting system also serve to distort the measured response from the ideal.

In order to use a large receiving antenna effectively, a method of removing the response characteristics of all systems involved but the target is needed. A measurement of the transmitted signal directly by the receiving antenna without a target present contains all distorting response characteristics that are to be removed from the measured target response and serves as a base response. Deconvolving the base response from the target response leaves the pure impulse response of the target as desired.

Deconvolution is carried out with real time measured data by the use of matrices. The matrix equation arrived at is $E \cdot H = R$ where E is a matrix fashioned from the base response, R is a vector containing the response from the target and H is a vector representing the impulse response for which we are solving. This equation is illconditioned, and directly solving it for data containing noise yields results which, while mathematically correct, are physically nonsense. The solution is instead found by altering the matrix equation slightly through the use of a parameter, p, to achieve another matrix equation

$$E^t \cdot E \cdot H + p \cdot H = E^t \cdot R$$

which is approximately the original equation but which is significantly less ill-conditioned.

Implementation of this method will be discussed along with application to real measured data and the results obtained for a target whose theoretical response is known.

EXPANSION OF K-PULSE IN TERMS OF LEGENDRE POLYNOMIALS FOR AN ARBITRARY TARGET [1]

Gonul TURHAN and David L. MOFFATT

The Ohio State University ElectroScience Lab
Department of Electrical Engineering
Columbus, Ohio 43212

The K-Pulse is an excitation waveform of minimal finite duration producing a time-limited response. The Laplace transform of the K-Pulse should be an entire function having the distribution of zeroes which coincides with the distribution of poles of the target under consideration.

In this paper, we will discuss a special inversion technique to approximate the K-Pulse for an arbitrary target. Since the K-Pulse is a time-limited function, this permits one to use an expansion in terms of Legendre polynomials which form a complete, orthogonal set of basis functions over a bounded time interval. The weighting coefficients of this expansion can be obtained using the pole distribution of the target only.

There is an indication from the behaviour of the expansion coefficients that a delta function type of singularity may occur in the K-Pulse for some targets. In such a case, the position and the weighting for the impulse term need to be estimated before proceeding to find the coefficients of the Legendre Series for the regular part of the K-Pulse.A possible approach to this problem is proposed.

Applications of the proposed method to different target geometries will be presented and the numerical difficulties encountered will be discussed.

[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.

SALON 10
B-12—SPECIAL SESSION ON FRACTALS
Chairman: D.L. Jaggard
TUESDAY-PM

AN INTRODUCTION TO FRACTAL CONCEPTS IN DISORDERED MATERIALS

D. A. Weitz
Exxon Research and Engineering Co.
Rt. 22 East, Annandale, NJ 08801

The first step in a quantitative account of the physical properties and behavior of any material is necessarily a quantitative description of its structure. Nevertheless, there exists in nature a large and commonly encountered class of materials whose structure is so highly disordered that it has, until recently, defied quantitative characterization. However, the introduction of the concepts of fractals has dramatically changed this, making the structure, and physical properties, of a large subset of disordered materials accessable to quantitative characterization. In this talk, we will introduce the basic concepts of fractal geometry, and demonstrate how it has been successfully applied to describe the structure of a variety of materials. The emphasis will be on developing a physical picture of fractal structures, and several examples will be discussed in more detail to illustrate both their structure and physical properties. In addition, a brief description of some growth processes which can lead to fractal structures will be presented.

The key property which distinguishes fractal structures is their invariance under a change in length scale. Thus, if a fractal object were viewed under a microscope, it would have the same appearance for all scales of magnification. As a consequence, a fractal possesses no characteristic length scale, but rather has structural features on all length scales. This scale invariance is, in fact, a form of symmetry, and is called dilation symmetry. Of course, for any fractal material found in nature, scale invariance can exist only over a finite range of length scales, and thus the fractal behavior is bounded both above and below. Furthermore, all natural fractal materials are random and thus, their invariance under dilation is true in a statistical sense rather than an exact sense.

A fractal material can be characterized by the scaling of mass with length scale, $M \sim R^{d_f}$, where d_f is called the fractal dimension and is typically not an integer, and less than the dimension of space.

One of the most appealing features of a fractal description of disordered materials is that the dimensions which characterize the structure have a clear geometric significance, making possible a visualization of their significance. This talk will demonstrate this with reference to specific examples of disordered materials.

THE FRACTAL NATURE OF TURBULENT DIFFUSION

Michael F. Shlesinger, Office of Naval Research, Physics Division, 800 North Quincy Street, Arlington, Virginia 22217-5000

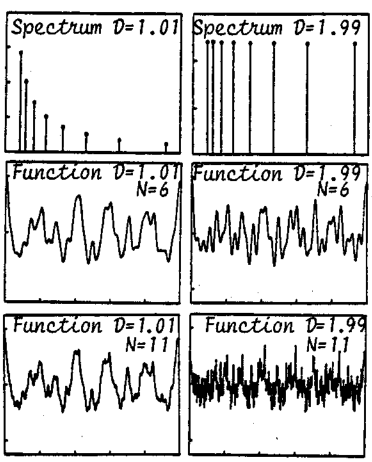
We introduce a stochastic process, called a Levy Walk, which describes random (but still correlated) motion in space and time in a scaling fashion. The process can be represented by either a generalized master equation or a random walk with nonlocal memory coupled in both space and time. We apply our correlated random walk model to the description of fluctuating fluid flow so that when Kolmogorov's -5/3 law for homogeneous turbulence determines the memory function, then Richardson's 4/3 law law of turbulent diffusion for a passive scalar follows. If, as suggested by Mandelbrot, turbulence is fractally homogeneous, then intermittency corrections to the -5/3 law follow in a natural fashion.

BANDLIMITED FRACTALS AND WAVE PROPAGATION

D.L. Jaggard and Y. Kim
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Fractals are irregular, non-differentiable, fragments that possess the underlying order of self similarity on all scales. They were introduced by Mandelbrot, circa 1977, to describe naturally occurring topography and structures and to generate new synthetic structures. It appears, however, that many of the structures of interest in wave propagation are fractal over a limited range of scales. For example, in turbulence theory a finite number of scale lengths are used. For this reason we introduce the concept of bandlimited fractals as embodied in a modified Weierstrass function.

We use as a model of one-dimensional bandlimited fractal medium, a modified Weierstrass function with N tones (i.e., N lines in the spectrum) and fractal dimension D ($1<D<2$) to describe the refractive index variation. Here D exceeds the topological dimension D_T where the latter is taken to be unity. Therefore, small D represents gentle variations described by smooth curves while large D represents rapid irregular variations described by space filling curves. Examples of these functions are given in the accompanying figure where the spectrum and modified Weierstrass function are plotted for various combinations of D and N. Ordered media are represented by $D\gtrsim 1$ and N small whereas disordered media are represented by $D\lesssim 2$ and N large. In this way bandlimited fractals provide a unifying scheme for describing a wide variety of interesting and important media, both ordered and disordered.



Here we examine wave propagation in the above described medium by developing a generalized Floquet solution to the appropriate Helmholtz equation. Investigations are underway to describe dispersion and reflection properties of the medium and to relate this approach to the corresponding deterministic and statistical approaches.

NON-GAUSSIAN FRACTAL PHASE SCREENS

David H. Berman
U.S. Naval Research Laboratory
Washington, DC 20375-5000

Recent evidence indicates that single and two-point statistics of ocean bottom heights are non-Gaussian. In addition, the spectrum of ocean bottom heights, i.e. the Fourier transform of the height-height correlation function, exhibits inverse power-law dependence on wave number. For these reasons, ocean bathymetry might be characterized as a non-Gaussian fractal. The fractal dimension appears to be less than 3/2 and the statistics of the bathymetry are adequately described by K-distributions. This paper investigates consequences of these facts for underwater acoustic scattering by examining the statistics of an acoustic field far behind a K-distributed fractal phase screen. In the case of Gaussian phase screens it is known that far from the screen, the scintillation index of the field saturates at its Rayleigh value of 1. In the case of K-distributed phase screens, the scintillation index again saturates to the Rayleigh value. However, for extremely non-Gaussian screens with fractal dimension $D < 3/2$, the rate of approach to the asymptotic limit is considerably slower than for Gaussian screens. In addition, in this last case the scintillation index approaches 1 from below rather than from above as in the Gaussian case. This means that signal detection might be easier than in the case of a Gaussian phase screen because intensity fluctuations are more constrained.

THEORY OF THE AC RESPONSE OF FRACTAL INTERFACES

S. H. Liu

Solid State Division, Oak Ridge National Laboratory
Oak Ridge, TN 37830

ABSTRACT

The electrical properties of the interface between a metal electrode and an aqueous or solid electrolyte are important problems in electrochemistry and related technology because they affect the performance of electrochemical devices. In the classical theory an alternating current driven through the interface is expected to encounter an interfacial capacitance in series with the ohmic resistance in the electrolyte. The predicted frequency dependence of the impedance is very simple, i.e. the real part is independent of the frequency and the imaginary part is inversely proportional to the frequency. In reality, however, such an RC circuit does not give an adequate description of the ac response of the interface. It is often necessary to include a so-called constant-phase-angle (CPA) element whose impedance has the form $Z \propto (j\omega)^{-\eta}$, where ω is the angular frequency and the exponent η satisfies $0 < \eta < 1$. In recent years it has been demonstrated by many authors that this unusual circuit element originates from the microscopic roughness of the interface. When the interface is made increasingly smooth, the exponent approaches unity. We propose to model the rough interface by fractals, and derive on the basis of a number of regular as well as random fractal models that η is related to the fractal dimension of the interface d_S by $\eta = 3 - d_S$. Experiments are under way to check how well this relation is obeyed by real interfaces.

Research sponsored by the Division of Materials Sciences, U. S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

SCATTERING OF WAVES AND PARTICLES FROM FRACTAL OBJECTS

D. A. Weitz
Exxon Research and Engineering Co.
Rt. 22 East, Annandale, NJ 08801

Through the use of of concepts fractals or scale invariance, it is now possible to quantitatively describe the structure and physical properties of a wide class of highly disordered materials. A fundamental property of fractal objects is the behavior of their density-density correlation function, $g(r) \sim r^{-\alpha}$ where the co-dimension is $\alpha = d - d_f$, with d the Euclidean dimension of space, and d_f the fractal dimension which directly characterizes the material. The form of the correlation function will be reflected directly in the coherent scattering of either waves or particles from a fractal, as the scattering function is simply the Fourier transform of the correlation function. Indeed, scattering techniques are a powerful way of actually measuring the structure of fractal objects. In this paper, we discuss in detail the scattering of light, X-rays and neutrons from a prototypic fractal object.

The samples used are aggregated aqueous gold colloids, whose highly disordered structures are very well characterized as fractals. Furthermore, while the colloids represent an easily controlled and well characterized example of kinetic growth, similar behavior is expected for a wide variety of other growth processes, and the insight gained from this study should be quite generally applicable. We study the scattering intensity as a function of the scattered wave vector, S(q), which represents a Fourier transform of the density-density correlations of the aggregate. The most detailed information comes from a small angle X-ray scattering experiment performed with synchrotron radiation, and extending over nearly three decades in q, from $\sim 3 \times 10^{-4}$ to $\sim 8 \times 10^{-2}$ Å^{-1}. The data is interpreted with a model which includes the form factor of the individual spheres, the short range packing of the nearest neighbors and the long range fractal correlations of the aggregate.

The scattering of both neutrons and light correspond very closely to that of X-rays, although each of these probe a much smaller range in q. The scattering of light is complicated by the fact that the gold spheres possess an electronic plasma absorption resonance, which leads to a concomitant increase in the scattering intensity. We will discuss measurements of the q and frequency dependence of both the polarized and depolarized scattering as well as the frequency dependence of the absorption, and compare these to the results of a self-consistent calculation of the scattering including terms to the electric dipole order.

SELF-SIMILAR FRACTALS AND FOURIER TRANSFORMS

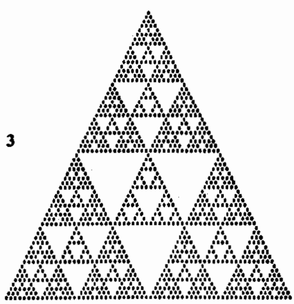
Akhlesh Lakhtakia, Vijay K. Varadan and Vasundara V. Varadan
Laboratory for Electromagnetic and Acoustic Research
Department of Engineering Science and Mechanics
The Pennsylvania State University
UNIVERSITY PARK, PA 16802

In recent years, investigations into the geometry of matter have revealed fundamental discrepancies between Euclidean geometry and the geometry of naturally-occurring structures. Euclidean geometry is characterized by integral dimensions D: a line is unidimensional (D = 1), a plane is bidimensional (D = 2), and so on. However, as Mandelbrot (*The Fractal Geometry of Nature*, New York: Freeman, 1983) has argued successfully, a highly zigzag line *tends* to fill up an area; hence, its *dimension* should be between 1 and 2 as opposed to its Euclidean dimension of unity. Arguments of like nature can be invoked for objects of higher Euclidean dimensions as well, and, as such, the concept of *fractal*, or non-integral, dimension d seems to be well-founded. Fractal structures are characterized by several properties, of which a more notable one is their *scale-invariance*. Strictly geometric fractals can be constructed which possess scale-invariance in the form of self-similarity, among the more notable ones being the Koch triad and the Sierpinski gasket.

Since the procedure of taking the Fourier transform is a linear process, it can be shown that the Fourier transforms of self-similar geometrical fractals are themselves self-similar fractals. Thus, such fractals appear to be of significance for diverse EM problems, including the synthesis of active/passive arrays and the design of SAW filters, microstripline circuitry, etc.

Procedures for constructing self-similar arrays will be examined. A generalisation of the Sierpinski gasket, named the Pascal-Sierpinski gaskets, will be introduced here, and their Fourier transforms and scale-invariance investigated. Diffraction by a simple Sierpinski gasket screen and a Sierpinski carpet screen will be discussed to show the potential use of geometric fractals in array problems.

The Pascal-Sierpinski gasket of order 3



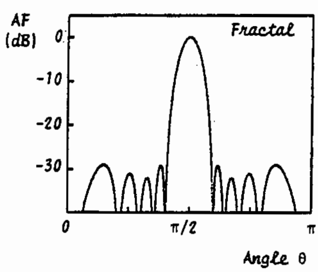
FRACTAL VIEWPOINT OF LINEAR ARRAY THEORY

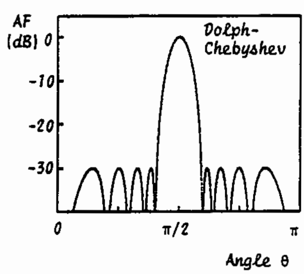
Y. Kim and D.L. Jaggard
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

A novel method of linear antenna array classification and synthesis is presented. This new method relies on the application of fractals and the introduction of a density parameter to the problem of linear antenna array theory.

Fractals were introduced by Mandelbrot to describe naturally occurring fragmented and irregular geometries which exhibit self-similarity. The underlying order inherent in fractals provides a simple procedure to create a variety of complicated appearing and very useful geometries.

Here, we introduce the concept of fractals to the area of antenna array theory because this underlying order is also present in the antenna array problem. In particular, we make use of fractal geometry to find a novel procedure for placing discrete points (array elements) on a line in order to produce useful characteristics (radiation patterns) and to classify existing structures. To do this we develop a fractal signal flow graph which is appropriate for antenna array problems. In order to produce a desirable radiation pattern, the fractal signal flow graph is controlled by the density parameter which specifies the location of the array zeros on the unit circle. Based on this idea, a variety of uniformly spaced arrays can be classified and synthesized. As an example, the array factor of 10 element broadside array using this method is compared with Dolph-Chebyshev array with the same null-to-null bandwidth. This almost optimized fractal array has comparable characteristics to the Dolph-Chebyshev array as shown in the figure below. The step by step synthesis procedure will be addressed.





A BACKSCATTERING MODEL FOR VARIOUS FOLIATED DECIDUOUS TREE TYPES AT MILLIMETER WAVELENGTHS

C.C. Borel, R.E. McIntosh
Microwave Remote Sensing Laboratory
Departement of Electrical and Computer Engineering
University of Massachusetts
Amherst, MA 01003, USA

This paper develops a model for foliated deciduous trees for frequencies above 35 GHz using geometrical optics. The leaf is modeled as a segment of a thin spherical shell of dielectric material, made of a mixture of water and solid material. The orientation of the leaves is determined using one out of five different probablity densities for the leaf inclination angle. The leaf diameter and the radius of curvature are other parameters considered in the model. The position of the leaves is computed by a fractal theory model for the structure of trees, which is able to generate many different tree types using different branching angles.

A computer simulation computes the normalized radar cross section (NRCS) for a small area of the tree viewed from an arbitrary point with ray tracing techniques. These NRCS-pixels form then a picture of the tree and indicate that the scattering intensity is also a function of the position. The NRCS computation takes shadowing and absorbtion into account.

PHILA. NORTH
B-13—GUIDED WAVES
Chairman: S.T. Peng
WEDNESDAY-PM

CUTOFF CHARACTERISTICS OF FIRST HIGHER-ORDER MODE OF ELLIPTICAL FIBERS

Sembiam R. Rengarajan
Department of Electrical and Computer Engineering
California State University, Northridge
Northridge, CA 91330

Cutoff frequency characteristics of two-layer step index elliptical fibers in the literature are reviewed. For the limiting case of unity eccentricity, modes and field distribution in elliptical fibers are shown to be different from those of a dielectric slab. However, a correspondence between the first higher order mode cutoff frequency between rectangular and elliptical fibers is presented. From mode correspondence and other physical considerations, confidence in the results of a previous publication (Rengarajan and Lewis, Electron Lett., vol. 16, no. 7, 1980) is established. The results of a recent paper (Saad, IEEE Trans, M.T.T., vol. MTT-33, no. 11, 1985) are shown to have limitations.

APPLICATION OF THE SCALAR WAVE-FAST FOURIER TRANSFORM TECHNIQUE TO WEAKLY GUIDING DIELECTRIC COUPLERS, HORNS, AND BRANCHES

F. Manshadi
Jet Propulsion Laboratory, Pasadena, CA

C. W. Yeh
University of California, Los Angeles, CA.

The Scalar Wave-Fast Fourier Transform Technique (SW-FFT) has been shown to be a powerful tool in solving the problem of wave propagation along weakly guiding optical waveguides (F. Manshadi, C.W. Yeh, Proceedings of 1985 North American Radio Science meeting, Vancouver, B.C. pp. 177). The technique is based on the solution of the scalar wave equation by the forward-marching fast fourier transform method and is applicable to dielectric waveguides of arbitrary shape and three dimensional refraction index variation. The solution yields the spatial configuration of the field and its power intensity along the guiding structure. A subsequent spectrum analysis performed on the power intensity provides the modal characteristics of the field such as the propagation constant and the relative amplitude of each mode (M.D. Feit, J.A. Fleck, Jr., appl. optics, 19, 1154-1164, 1980). This technique has been successfully applied to several simple optical waveguides such as, step-index circular fiber, graded index circular fiber, elliptical, triangular, and rectangular dielectric waveguides. The validity of these results were proved by comparing them with solutions obtained by other known exact and approximate methods.

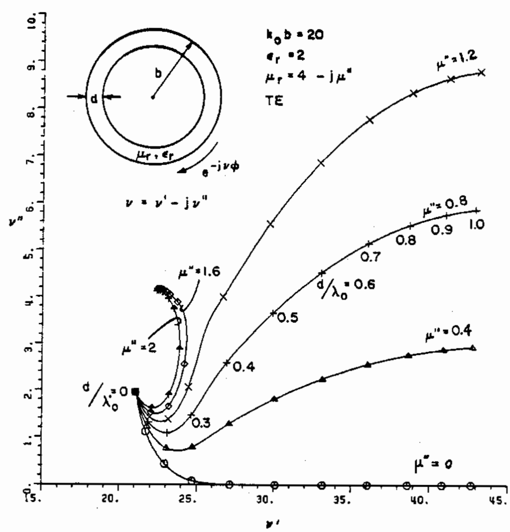
In this paper, the SW-FFT technique is applied to some more complex multi-dimensional problems such as dielectric waveguide couplers, horns, and branches. The spatial configuration of the field along these guiding structures, as well as the modal characteristics of the field, is computed and the solutions are compared to the results obtained by other methods where they were available. This paper will establish the fact that the SW-FFT technique is not only useful in analyzing simple geometries, but that it is quite powerful in treating complex guiding structures where exact solutions are not readily available.

CREEPING WAVE PROPAGATION ON CONDUCTING CYLINDERS COATED WITH LOSSY FERRITE MATERIAL [1]

Hyo-Tae Kim and Nan Wang

The Ohio State University ElectroScience Lab
Department of Electrical Engineering
Columbus, Ohio 43212

The creeping waves supported by a conducting cylinder with a lossy ferrite material coating are investigated. Numerical values for the propagation constants of the creeping waves are obtained by seeking the roots of a transcendental equation which characterizes the coated cylinder. Typical trajectories for the propagation constants in the complex v-plane are shown in the figure below. Note that the creeping wave propagates as exp(-jvϕ). The propagation constants of the creeping waves for the coated cylinder, the impedance cylinder (conducting cylinder with a constant surface impedance), and the planar coated conductor will be compared. A useful quantity, namely, the modal impedance associated with the creeping waves will also be presented.



[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.

NEW METHOD FOR THE ANALYSIS OF SURFACE WAVES

S. T. Peng

Electromagnetics Laboratory
New York Institute of Technology
Old Westbury, NY 11568

and

S. L. Wang

Department of Mathematics
University of New Haven
West Haven, CT 06516

ABSTRACT

A new method is presented for the analysis of surface waves that are guided along a dielectric layer in a uniform environment. Firstly, the dispersion relations for various mode types are cast in a new form that are particularly simple and useful for mathematical and physical interpretations of the surface waves. Secondly, a new iteration procedure is developed, which offers two major advantages: (1) The first order approximation yields a simple analytic expression that is sufficiently accurate for most practical applications. (2) The iteration procedure converges monotonically and rapidly. In addition, it is shown that the new form of the dispersion relations provides a unified approach to both dielectric and metallic waveguides.

DISPERSION ANALYSIS OF MICROSTRIP-LIKE TRANSMISSION LINES ON A LARGE CLASS OF ANISOTROPIC SUBSTRATES

R. Marqués and M. Horno
Departamento de Electricidad y Electrónica. Facultad de Física.
41012-Sevilla. SPAIN.

Lately, considerable attention has been paid to finding the dispersion characteristics of microstrip-like transmission lines on anisotropic substrates. In the present work, the authors show a method to find the effective dielectric constant of microstrip-like transmission lines as a function of frequency, provided that the direction perpendicular to the ground-plane -i.e., the y-axis- is also a main axis of anisotropy. The scope of this method includes microstrips on uniaxial and biaxial dielectric substrates -when the condition mentioned aboved is fulfilled- and magnetized plasmas in a magnetostatic field perpendicular to the ground-plane.

The analysis follows usual spectral domain techniques and Galerkin's method, with apropriate trial functions for density of current on the strips. When the tensor of anisotropy is properly oriented, one arrives at a second order wave equation along y-direction (with a matrix as a coefficient) for some auxiliar field vector that is a linear transformation of the field components $\tilde{E}_z$ and $\tilde{E}_y$ in the spectral domain. After including the boundary conditions a dyadic Green's function $\bar{\bar{\zeta}}$, is obtained in a simple and closed form:

$$\begin{bmatrix} \tilde{E}_z \\ \tilde{E}_x \end{bmatrix} = j\omega\mu_0 \bar{\bar{\zeta}} \begin{bmatrix} \tilde{J}_z \\ \tilde{J}_x \end{bmatrix} \quad ; \quad \bar{\bar{\zeta}} = \left\{ \bar{\bar{Q}}^{-1} \begin{pmatrix} f_1 & 0 \\ 0 & f_2 \end{pmatrix} \bar{\bar{Q}} + k_0^2 \Gamma \bar{\bar{\varepsilon}}_{\perp} \right\}^{-1}$$

where $\varepsilon_{\perp}$ is the anisotropic tensor in the x-z plane, f_1, f_2 and Γ some analytical simple functions -in fact, combinations of rational and hyperbolic functions-of the meaningful quantities of the problem, and Q the linear transformation mentioned aboved, i.e., a rotation matrix around the y-axis of angle $\gamma = \sin^{-1}(\alpha^2+\beta^2)^{1/2}$, where α is the transformed Fourier variable of x, and β the propagation constant along z.

To check the accuracy of the method, our results have been compared with those available in literature (T.C. Edwards et al. IEEE-MTT-24, pp 506-513) which coincide nearly.

As an example we have computed the dispersion characteristics of a microstrip on a uniaxial substate of boron-nitride, when the optical axis ($\varepsilon^* = 3.4$) is either in the y-direction (Fig. 1, curve 1) or in the z-x plane at an arbitrary orientation (curves 2, 3,4 -θ is the angle between optical axis and the direction of propagation, z). The method has also been used to obtain the dispersion characteristics of bilateral fin-line structures.

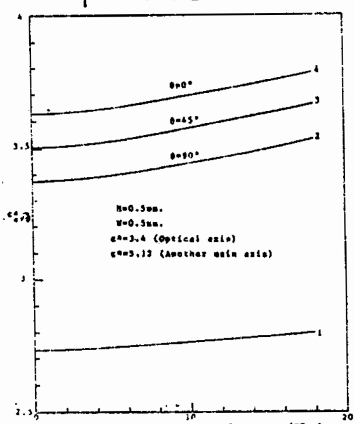


Fig. 1

PREDICTION OF LASER WAVELENGTH FOR MINIMUM TOTAL DISPERSION IN SINGLE-MODE GRADED-INDEX FIBRES

A.ALPHONES and G.S.SANYAL
Centre for Research and Training in Radar and Communication, Indian Institute of Technology, Kharagpur, India - 721 302

The delay distortion of pulses in single-mode fibres results from a non-additive combination of dispersive effects that are due to the wavelength dependence of the refractive indices of the light-guide materials and also due to the wavelength dependence of the group delay of the single propagating mode. Here we have utilised the numerical techniques of differentiation and interpolation which was proposed by P.S.M.Pires (P.S.M. Pires, IEEE Trans.MTT,30,131-140,1982). For the computation of the normalised propagation constant of the fundamental mode, Gloge's approximate solution is used. The three term Sellmeir equation is utilised in this work. The optimum wavelength is computed for different profiles. Based on these results, design of single-mode graded index fibres for minimum dispersion is calculated with the normalised frequency range $1.0 \leq V \leq 2.5$.

DESIGN LIMITATIONS ON FINLINE FILTERS AND MATCHING NETWORKS

A.S. Omar and K. Schünemann
Technische Universität Hamburg-Harburg, Arbeitsbereich Hochfrequenztechnik, Postfach 90 14 03, D-2100 Hamburg 90, West Germany.

ABSTRACT

Design limitations on finline filters and matching networks are discussed. Lower and upper limits on some filter parameters are given in terms of finline parameters.

Narrow-band band-pass-filters are designed using the lumped element prototype networks. They are best implemented using inductive strip coupling between directly coupled finline resonators of 100% slot width, due to the weak coupling introduced by the inductive strips and the relatively high Q-factor of the 100% slot width finline resonators. Metal insert E-plane circuits give still better responses due to their higher Q-factors. Wider band width requires stronger coupling, which is achieved by narrower coupling strips. This puts an upper limit on the practically achievable band width. another upper limit is due to the frequency variations of the equivalent circuit elements, which model the coupling strips.

Wide-band filters and impedance-matching networks are designed using the stepped impedance prototype networks. Finline step discontinuities of moderate slot width ratios are best modelled by a transformer shunted by a weak inductance, because the first few high-order modes of a finline with moderate slot width are inductive. This makes such discontinuities best suited for wide-band filters and impedance-matching networks. Wider band width requires lower slot width ratios. In the limiting case one obtains a finline taper. A lower limit on the band width is put by the practically achievable slot width.

OPTICAL TIME DIVISION MULTIPLEXING DEVICE

K.A.AL-Kateeb/Proff.Ass.School of Elect.Eng.,University of Technology-Baghdad.
A.M.Jassim/Res.Ass. Space and Astronomy Research Centre.
A.M.Khidir/Eng.Ass. Space and Astronomy Research Centre.

ABSTRACT

An optical multiplexer-demultiplexer using Time Division Multiplexing (TDM) techology has been proposed. The dispersion equations of a multilayer structure in which the modulated light is guided by a main dielectric waveguide and then transferrd to secondary dielectric waveguides by changing the conductivity of an active silicon layer sandwitched in between have been derived.

Computer modelling studies indicate that a 90% power change in the secondary dielectric waveguide of 3 um thickness has been obtained for 25% silicon conductivity change when silicon thickness is about 0.3 um .It has been found that the width and spacing distance for each secondary dielectric waveguide are double and one tenth of the main dielectric waveguide thickness respectively which has been selected as 3 um in order to obtain an attenuation of less than 3 dB/mm.

SALON 3/4
B-14—ELECTROMAGNETIC THEORY I
Chairman: H.N. Kritikos
WEDNESDAY-PM

A NEW FORMULATION OF ELECTROMAGNETIC WAVE SCATTERING USING AN ON-SURFACE RADIATION BOUNDARY CONDITION APPROACH

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

Allen Taflove
Department of Electrical Engineering and Computer Science
Northwestern University
Evanston, IL 60201

Korada Umashankar
Department of Electrical Engineering and Computer Science
University of Illinois at Chicago
Chicago, IL 60680

A new formulation of electromagnetic wave scattering in two dimensions by convex conducting bodies is reported. This formulation is based upon a multipole expansion of the radiation condition, yielding a radiation boundary operator, B_n, which is an n-series having the usual Sommerfeld condition as the leading term. Past approaches involved applying B_n at some distance from the scatterer in order to achieve a nearly reflection-free truncation of a finite-difference time-domain lattice implementing a scalar or vector wave equation problem. However, it is now shown that B_n can be applied directly on the surface of convex-shaped conducting scatterers for frequency-domain problems. Substantial simplification of the overall TM or TE scattering formulation is achieved, since the original integral equation for the scattered field is reduced to merely a line integral. By varying the order, n, of B_n, it is shown that application of higher-order on-surface radiation conditions yields computed scattered fields which approach the classically-obtained results.

This paper applies the new theory to model TM and TE scattering by three canonical two-dimensional conducting geometries: the circular cylinder; the square cylinder; and the infinitely thin strip. Electrical sizes for the canonical problems are ka = 5 and ka = 10. Both surface currents and radar cross section are plotted. The simplicity of the new formulation, and its excellent accuracy, indicate that the on-surface radiation condition approach may present a useful alternative to present integral equation and uniform high-frequency approaches.

REDUCTION TO THE BOUNDARY AND OSRC

Charles F. Meyers
Lockheed Corporation
Sunnyvale, California 94086-3504

When truncating numerical grids, the radiation condition at infinity must be applied at a finite distance from the scatterer. This leads to the development of various higher-order radiation conditions. In May of 1985, Kriegsmann, Tafiove, and Umashankar observed that if the radiation conditions were applied on the surface, accurate results were obtained. At first this seems impossible, since the conditions are asymptotic. The method is slightly less mysterious when one relates it to certain developments in mathematics.

In the modern theory of partial differential equations, one of the main tools is a method due to Calderon of reducing a differential equation in a region to an equation on the boundary of the region. One problem is that the equation on the boundary is a pseudo-differential equation, not a differential equation. By approximating the pseudo-differential equation by a differential equation, one has rigorously reduced the original problem to a differential equation on the boundary. This is a step toward justifying the on-surface radiation condition.

This paper will explain what pseudo-differential operators are, and examine some differential approximations to them. Analogies with reduction of volume integral equations to surface integral equations, and advantages associated with the reduction in the differential case, will also be discussed.

EXTENSION OF ON-SURFACE RADIATION CONDITION THEORY TO SCATTERING BY TWO-DIMENSIONAL HOMOGENEOUS DIELECTRIC OBJECTS

Korada Umashankar
Department of Electrical Engineering and Computer Science
University of Illinois at Chicago
Chicago, IL 60680

Allen Taflove
Department of Electrical Engineering and Computer Science
Northwestern University
Evanston, IL 60201

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

The recent formulation of electromagnetic wave scattering by perfectly conducting two-dimensional objects using an on-surface radiation boundary condition theory is extended here to the case of two-dimensional homogeneous dielectric objects. This formulation is based upon a multipole expansion of the scattered electric and magnetic fields in the radiation zone, which generally yields a series of radiation boundary operators. Previously, these radiation boundary operators were successfully utilized for limiting large numerical lattice domains in finite-difference time-domain approaches for scalar or vector wave equations. In fact, the radiation boundary operators can be enforced near the surface of scatterers as well. This was demonstrated very recently for the case of TM and TE scattering by two-dimensional convex conducting cylinders (which is reported in another paper in this symposium). It was found that substantial simplifications can be obtained for both the induced surface electric current distributions and the corresponding monostatic radar cross sections.

This paper develops the on-surface radiation condition theory for TM and TE excitation of two-dimensional, homogeneous dielectric bodies of convex shape. Excellent validations of the near-surface electric and magnetic fields are reported for canonical cross-section shapes. Similar to the conducting cylinder cases, the application of the on-surface radiation condition theory results in substantial simplification of the analysis.

GREEN'S FUNCTION FOR RADIALLY-DIRECTED LINE DIPOLE

Chalmers M. Butler
Department of Electrical and Computer Engineering
Clemson University
Clemson, SC 29634-0915

Krzysztof A. Michalski
Department of Electrical Engineering
University of Mississippi
University, MS 38677

A method is presented by means of which one can construct a vector potential Green's function for a radially-directed line dipole in circular cylindrical coordinates, subject to the restriction that the line dipole is invariant along its length. An equation satisfied by a radially-directed component of vector potential is derived by choosing an appropriate relationship between the vector and scalar potentials. This equation is solved and field components are determined from this vector potential Green's function. The validity of the method is demonstrated by determining the field components by an alternate procedure and appealing to the uniqueness theorem. The alternate procedure is based upon an equivalence between electric and magnetic currents and a subsequence solution of the equation for a magnetic line doublet. It is demonstrated that the method of this paper is far more direct than the alternate procedure and, of more importance, that it can be extended to derive the Green's function for the radially-directed line dipole in the presence of a circular cylinder. Green's functions for electric and magnetic radially-directed line dipoles are given for such sources in the presence of perfectly conducting (electric and magnetic) cylinders and lossy dielectric cylinders.

GREEN'S FUNCTION FOR INHOMOGENEOUS MEDIA — A PATH-INTEGRAL APPROACH

S. K. Jeng* and C. H. Liu
Dept. of Electrical and Computer Engineering
University of Illinois
Urbana, IL 61801

Abstract

In the past the path-integral technique has been applied mostly in solving Schrödinger equation or diffusion type of equations. In this paper, this technique will be applied to construct the Green's function of a Helmholtz equation in a general inhomogeneous medium. It will be shown that the general Green's function can be expressed in terms of a path-integral followed by an one-fold integration. The advantage of such an expression is that once a closed form for the path-integral is obtained, the Green's function can be computed as a one-fold integral, even for general three-dimensional problems. Such closed form of the path-integral have been derived for inhomogeneous media with permittivity varying as a quadratic form of the coordinates. For the special case of a homogeneous medium with a constant refractive index, it will be shown that the well-known Green's functions are recovered. Furthermore, for the one-dimensional linearly-stratified media, for which the Green's function is also known, the path-integral results will be shown numerically to be identical as the familiar Airy function expression. It is worth emphasizing that the more important three-dimensional Green's function in such a medium can also be computed as efficiently as for the one-dimensional case. Results of such computation will be presented. Applications of these results to solve problems of radiation and scattering in inhomogeneous media will be also discussed.

*On leave from National Taiwan University, Taipei, Taiwan, R.O.C.

A DESCRIPTION OF THE LOCAL PROPAGATION OF ELECTROMAGNETIC FIELDS AS A FUNCTION OF DIRECTION

Francis X. Canning
Fuze and Sensors Department
Naval Weapons Center
China Lake, CA 93555

The concept of modal ray angle is quite useful in understanding the propagation of electromagnetic fields along uniform structures whose modes are well defined. A similar concept valid both for this case and additionally for the interior of non-uniform structures and for scattering from the exterior of structures is developed. This concept contains more information than the Poynting vector, much as knowledge of the modal ray angles in a uniform waveguide contains more information than the statement that on average the energy flow is along the axis of the guide.

The theoretical development herein begins by restricting our consideration to situations where the Parabolic Equation Approximation (i.e. the Para-Axial Approximation) is valid. In this approximation one may use the equivalent path integral formulation (J. B. Keller and D. W. McLaughlin, Am. Math Monthly, 82, 451-465, 1975). This formulation is geared to describing how the fields "propagate" in space. Unfortunately, the specific directions in which a large amount of the field is propagating are not manifestly evident in these equations.

An exact reformulation of the path integral formulation (of the parabolic equation approximation) is motivated and presented for two-dimensional problems. It is found that directions related to modal ray directions are manifestly evident in the resulting equations. A quantity which has an interpretation as a rough measure of the strength of the local field flow as a function of direction is defined. This quantity is calculated for several simple situations and compared to expected results.

Finally, it is noted that if a sufficiently accurate numerical description of the field in a region is available, the approach presented here allows a numerical calculation of this description of the field's flow. The computer time involved is quite modest. Thus, if one is able to calculate the field by any means, the method of description presented here may be applied, hopefully generating information that will be useful in understanding the interactions involved. A particularly useful application may be in non-uniform cavities in which one cannot directly use a ray-like description.

RADIATION FROM A POINT SOURCE IN AN ANISOTROPIC MEDIUM

J.H.M.T. van der Hijden, Schlumberger-Doll Research, Old Quarry Road, Ridgefield, CT 06877-4108

The wave propagation problem of calculating the radiation of elastic waves from a source in an anisotropic medium was formally solved by Duff (G. F. D. Duff, Phil. Trans. R. Soc. London A 252, 249-273, 1960), by using the standard method of multiple Fourier transforms. Duff's solution however contains integrals over the wave surface and integrals over the volume between the wave surface and the convex envelope of that surface. Because these wave surfaces can have cusps, Duff's solution is unsuitable for numerical calculation.

The far field approximate solution is known explicitly (E. A. Kraut, Reviews of Geophysics 1, 401-448, 1963, and M. J. Lighthill, Phil. Trans. R. Soc. London A 252, 397-470, 1960). It uses the Gaussian curvature of the slowness surface. Even this approximate solution is quite involved when computed numerically.

We present the solution as derived by using the Cagniard-de Hoop method. After applying the Cagniard-de Hoop method the answer has the form of a convolution of the input signal of the source with the explicitly obtained space-time Green's function ("system's response"), which clearly shows each feature of the time behavior of the field quantities at different locations and their dependence on the material parameters involved. The complexity of the solution is now reflected in the Cagniard-de Hoop contours that represent the mapping from real time to complex ray parameter. These contours can be computed quite easily. Therefore the final expressions are not only very elegant but also computationally friendly. We will show some examples of the results.

SOLUTION OF ELECTROMAGNETIC RADIATION PROBLEMS WITH THE CONTINUITY GAUGE

A. Konrad

General Electric Company
Corporate Research and Development
1 River Rd., Bldg.37, Rm.355
Schenectady, NY 12301

Formulations based on the Lorentz or Coulomb gauge automatically lead to integral equation formulations for radiation problems [1]. However, for inhomogeneous electromagnetic radiators the Green's functions are either non-existent or difficult to find and integrate. A new approach [2] lends itself to a differential equation formulation for radiation problems in which inhomogeneities and near fields are important. The idea is to introduce a new gauge which couples the magnetic vector potential $\overline{A}$ and the electric scalar potential V in a meaningful and manageable way [2].

The new gauge transformation, called the continuity gauge, can be derived from the continuity equation:

$$\mathrm{Div}(\sigma + j\omega\varepsilon)\overline{A} = -\,\mathrm{Div}(\,\overline{J}\,) \qquad (1)$$

With this gauge set, V satisfies the complex Laplace's equation [1]

$$\mathrm{Div}(\sigma + j\omega\varepsilon)\mathrm{Grad}(V) = 0 \qquad (2)$$

Once V is found from (2), Grad(V) may be substituted as a forcing function into the CurlCurl equation for $\overline{A}$

$$\mathrm{Curl}\,\frac{1}{\mu}\,\mathrm{Curl}(\,\overline{A}\,) + (\sigma + j\omega\varepsilon)j\omega\,\overline{A} = \overline{J} - (\sigma + j\omega\varepsilon)\mathrm{Grad}(V) \qquad (3)$$

where μ is permeability, σ is electric conductivity, ε is permittivity, ω is angular frequency and $\overline{J}$ is current density.

The above formulation for radiation problems based on the continuity gauge opens up new possibilities for antenna analysis. The presentation will include an example.

References

[1] J. D. Jackson, Classical Electrodynamics, New York: Wiley, 1962, pp.179-183.

[2] A. Konrad, "A differential equation formulation for radiation problems based on the continuity gauge instead of the Lorentz gauge," submitted to 1986 Int. IEEE A/P-S Symp./Nat. Radio Sci. Mtg., Philadelphia, PA, USA, June 9-13, 1986

[3] A. Konrad, "Three-dimensional finite element solution of anisotropic complex potential problems," J. Appl. Phys., Vol.53, No.11, Nov. 1982, pp.8408-8410.

A COMPARISON BETWEEN INTEGRAL EQUATIONS DERIVED FROM UNIQUENESS AND EQUIVALENCE THEOREMS TO ANALIZE CONDUCTOR BODIES WITH APERTURES

M.F. Catedra
Departamento de Radiacion
E.T.S.I. Telecomunicación
Universidad Politécnica de Madrid
Ciudad Universitaria. 28040 Madrid. Spain

ABSTRACT

Integral Equations (IE) derived from the Equivalence Theorem (R.F. Harrington. "Time-Harmonic Electromagnetic Fields" pp 106-108) have been used to solve problems of conductor bodies with apertures. The problem is splitted in two (internal and external) or more regions. Electric and magnetic currents are considered in order to satisfy the boundary conditions at the surfaces of conductors and apertures. The electric current on the conductors is the physical current that they actually support.

In another approach, the Uniqueness Theorem (D.S. Jones "Methods in Electromagnetic Wave Propagation", pp 474-476) can be used to solve this type of problems, what amounts to find the electromagnetic fields in each region. This can be accomplished, using surface electric currents only. To compute the fields in each region a surface boundary current is considered. Imposing the boundary conditions in the conductor and aperture surfaces, IE's can be obtained to compute these currents that are different from the physical currents on the conductors.

Small horns with symmetry of revolution have been analyzed by M.M. using both theorems. Agreement between numerical results and measurements for both methods is quite good but in some cases, using the Uniqueness Theorem Formulation can reduce computing time an order of magnitude.

SALON 5/6
B-15—PERIODIC STRUCTURES AND TRANSMISSION
Chairman: D.L. Sengupta
WEDNESDAY-PM

MULTIMODE NETWORK DESCRIPTIONS OF A PLANAR PERIODIC METAL STRIP GRATING AT A DIELECTRIC INTERFACE

M. Guglielmi and A. A. Oliner
Polytechnic Institute of New York
Brooklyn, New York 11201

Integral equation solutions that lead to multimode network descriptions are presented for the problem of a plane wave incident at an angle on a zero-thickness periodic metal strip grating of infinite extent, placed at an air-dielectric interface. The grating period is taken to be large, so that the incident wave can produce more than one propagating spectral order. The motivation for this study is that this structure is a key constituent in a class of leaky wave antennas for millimeter wavelengths, and the results are presently being utilized in that context.

The problem has been phrased in terms of integral equations whose kernels contain an infinite sum of "static" modes, and the solutions obtained lead to network descriptions that are valid over different ranges of the parameter a/p (a = aperture size, p = grating period). We have derived a small aperture solution, a small obstacle solution and a third solution that, although rigorous in principle, requires the evaluation of infinite sums.

A reference solution is also presented for an incident TE wave, obtained via the reduction of the boundary value problem to a Riemann-Hilbert formulation. The solution has very good convergence properties and is shown to be very accurate, via comparisons with rigorous solutions available in the literature for special cases.

Finally, a comparison of all the results obtained shows that the small aperture and the small obstacle results are very accurate in their regions of applicability, and that the third solution exhibits a good convergence over the small and mid-size aperture ranges. The three solutions developed cover the whole range of variation of the parameter a/p, thereby constituting a powerful tool for the investigation of more complex structures containing the discontinuity under examination.

ANALYSIS OF DIELECTRIC CROSSED GRATINGS

S. T. Peng, C. M. Lu and P. Hui

Electromagnetics Laboratory
New York Institute of Technology
Old Westbury, NY 11568

ABSTRACT

A rigorous analysis is presented for a class of crossed gratings which are composed of a dielectric layer with periodic corrugations on both of its surfaces. For simplicity, each corrugated layer will be referred to as a simple grating. Such a composite structure is amendable to an exact formulation in terms of interactions between the two simple gratings. Therefore, it offers reliable numerical data against which the accuracy of other approximate ones can be judged. Depending on the relative orientations of the two gratings, the structure may be periodic in one dimension or in two dimensions with two different periods. To illustrate the effect of the relative orientations of the two gratings, numerical results will be given to show interesting wave phenomena that may take place in the crossed gratings.

WAVE SCATTERING FROM A DIELECTRIC PERIODIC GRATING WITH FINITE EXTENT

Mikio Tsuji and Hiroshi Shigesawa
Doshisha University, Kyoto 602, Japan

Numerical methods for the scattering problem of dielectric periodic gratings appeared so far are effective only for the gratings with infinite extent, and there is no effective method to know the effect of the finite extent of gratings. This paper present a new method useful for such a problem (Fig.1). The present authors have proposed the unprecedented network approach for the dielectric periodic structures with finite length from the view point of the open dielectric waveguide problem (H.Shigesawa et al.,1985 IEEE/MTTS Symp.,Y-2). Our approach leads that the periodic structure including the radiation phenomena can be expressed by the cascaded connection of the equivalent network shown in Fig.2. It should be noted here that the ports of the continuous spectrum do not correspond to a field distribution defined by an eigenvalue like the surface wave, but correspond to a wave group having the continuous spectrum expressed by one of Legendre functions. The functional form of the continuous spectrum part changes as the wave propagates along the uniform guide. This means that complex amplitude of a wave group expressed by a Legendre function changes continuously along the uniform guide. As a result, it is necessary to introduce the equivalent circuits R1 and R2 expressing the coupling between wave groups in a uniform guide section as shown in Fig.2. For applying this network approach to the scattering problem, we should consider that the partial periodic structure is connected not with the uniform waveguides, but the free space at its input and output terminals. In this case, we have only to take the Legendre transform of the incident wave at the input terminal plane to know the amplitude of the incoming wave of each terminal port at the input plane. After solving the all-over network problem of cascaded connection of the network shown in Fig.2, we can solve the outgoing-wave spectrum at the input and the output terminals, thereby calculating the scattering fields by the well known SDP method. In the oral presentation, the numerical results for the Gaussian beam incident on the finite periodic gratings will be included.

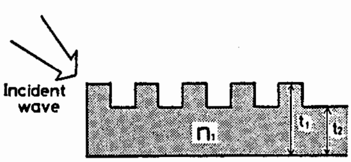


Fig.1. Dielectric periodic grating.

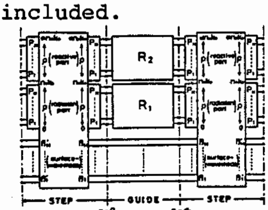


Fig.2. Equivalent network.

ELECTROMAGNETIC ANALYSIS OF DIELECTRIC HONEYCOMB SUPPORTS FOR FREQUENCY SELECTIVE SURFACES

Roy E. Jorgenson and Raj Mittra
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

H.Ohta, K.C. Lang and T.K.Wu
Space and Communications Group
Hughes Aircraft Company, El Segundo, CA

A frequency selective surface used in satellite applications is structurally supported by a dielectric slab that must be light-weight yet strong. Structured dielectrics are the preferred support material since they have a higher strength to weight ratio than do simple dielectrics. One such structured dielectric is the dielectric honeycomb. Since the honeycomb backing affects the characteristics of the frequency selective surface, it is important to be able to characterize the behavior of an electromagnetic wave in the presence of a slab of dielectric honeycomb.

In this paper we will do a full wave analysis of a plane wave incident on a slightly-lossy, low-contrast, dielectric honeycomb slab shown in Figure 1. The dielectric is replaced by an equivalent polarization current in free space and convolved over the unit cell with the periodic Green's function to obtain an integral equation. The equation is solved via the method of moments. Results are given in the form of a generalized scattering matrix which can be cascaded to obtain the scattering parameters for slabs of arbitrary thickness. The results are compared with those obtained by effective medium theories and experimental data.

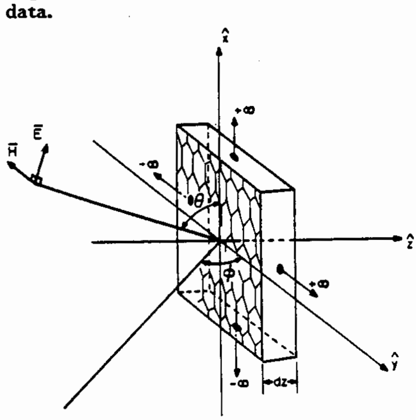


Figure 1. Geometry of the honeycomb slab

ON THE ELECTROMAGNETIC WAVE SCATTERING FROM INFINITE RECTANGULAR GRIDS MADE OF COATED CONDUCTORS OR ALLOYS

C.G. Christodoulou
University of Central Florida
P.O. Box 25000
Orlando, FL. 32816

J.F. Kauffman
North Carolina State University
P.O. Box 7911
Raleigh, NC. 27695-7911

The conjugate gradient method, in conjunction with the fast Fourier transform is employed to solve the problem of scattering from gratings and rectangular grids that are made of coated substrates or alloys. In some applications, the wires used to construct the grids are plated over with highly conducting materials such as gold or silver. In those cases, depending on the frequency of operation, the coating may not be thick enough to prevent currents from flowing in the substrate. The impedance of the wires is then governed by the conductivities of both the substrate and the coating materials. The conjugate gradient method can be used to study the problem of scattering from such infinite gratings and grids. An internal impedance is utilized to account for the effect of the substrate conductivity on the induced current densities. Another impedance expression is used for the case where the wires are made of alloys. Calculated values of the reflection coefficient and induced currents for different coating thicknesses, angles of incidence and polarizations are presented and discussed. Comparisons of those results with other methods are also offered.

END ADMITTANCES OF A TRUNCATED STRIP LINE OF FINITE WIDTH AND A TWO-WIRE TRANSMISSION

David C. Chang and Robert Johnk
Department of Electrical and Computer Engineering
Electromagnetics Laboratory
Campus Box 425
University of Colorado, Boulder
Boulder, Colorado 80309

There has been a renewed interest in finding the end admittances of a truncated strip line and a two-wire transmission-line recently because they represent the basis for analysis of many printed-circuit antenna structures. In the case of a two-wire transmission-line, a formally-exact expression for the end susceptance in the form of an infinite integral, can be obtained via the Wiener-Hopf type of formulation. It was pointed out, however, that this integral representation is not amenable to closed-form expression except for an unrealistically large aspect ratio, i.e., $\ell n\ b/a \gg 1$ where b and a are respectively the separation and the radius of the two-wire line (T.T. Wu, J. Applied Math, 2, 4, 551-573, 1961). Furthermore, it is also very awkward to extend the more general case of a strip line of finite width, even though the approximate transverse distribution of current is usually known.

In this paper, the reflection coefficient of a truncated strip line is obtained based upon the so-called bi-variational approach. The same leading term for the end-admittance can be recovered by using a current trial-function corresponding to an idealized open-end transmission-line. However, further refinement is possible with a trial function where the amplitude of the reflected current is determined by evoking the Raleigh-Ritz principle. To assure the continuity of current at the open end, a small section of finite-length is first assumed and a sinusoidal base-current used. A surprisingly simple closed-form expression can be obtained when the length of the small section is chosen optimally; its value is within a few percent of the exact integral representation even for a relatively low aspect ratio of, say, $\ell n\ b/a \geq 2.5$.

Since the formulation is variational in nature, extension to the case of a strip line of finite width can be carried out using approximate current distribution determined previously by Kuester and Chang (IEEE/MTT, 28, 3, 254-259, 1980), and performing the double-integration in the transverse-direction numerically. The dynamic nature of the end-susceptance for a strip line with a small aspect ratio now exhibits itself explicitly in the derivation. The end-conductance also no longer varies with the frequency square as is the case for the two-wire transmission-line as well as strip lines of high aspect-ratio.

NUMERICAL SOLUTION OF PLANAR INTEGRATED CIRCUIT DISCONTINUITIES WITH UNKNOWNS IN THE PLANE OF THE METALLIZATION

Kevin J. Webb
Electrical Engineering Department
University of Maryland
College Park, Maryland 20742

Raj Mittra
Department of Electrical and Computer Engineering
University of Illinois
Urbana, Illinois 61801

Discontinuities are frequently employed in microwave and millimeter-wave integrated circuits, for example in the realization of filters and matching structures. Consider a discontinuity consisting of a single or double step change in the microstrip strip width or the finline slot width. At higher frequencies the so called "full-wave" solution is necessary to achieve sufficient accuracy. Mode matching solutions have been presented (H. ElHennawy and K. Schunemann, IEE Proc. Pt. H, vol. 129, pp. 342-350, Dec. 1982), and a variationally stable iterative solution using an unknown magnetic current in the transverse junction plane was recently published (K. Webb and R. Mittra, IEEE Trans. Microwave Theory Tech., vol. MTT-33, pp. 1004-1010, Oct. 1985). A major difficulty with these approaches is that in order to achieve accurate results it is necessary to find satisfactory solutions for a large number of waveguide modes. The solution for these modes is both difficult and time-consuming.

We have been investigating an alternate approach which uses a two-dimensional spectral relationship in the plane of the metallization. This is an exact relationship between electric currents and electric fields, and avoids the need to find a large number of modes. The moment method provides a satisfactory solution. The novel aspects of our work are the containment of the semi-infinite problem, and the efficient evaluation of the spectral domain inner products. Results obtained for various discontinuity problems will be presented.

A TRANSMISSION LINE MODEL FOR MAGNETIC WAVES ON A THIN FILM

S. R. Seshadri
Department of Electrical and Computer Engineering
University of Wisconsin-Madison, Madison, Wisconsin 53706

A planar magnetic film occupies the region $-\infty<x,y<+\infty$ and $-a<z<a$ and is uniformly magnetized normal to the midplane $z=0$, that is in the z direction. The region outside the film is free space. The two-dimensional problem $(\partial/\partial y=0)$ in the magnetostatic approximation $(\nabla\times\underset{\sim}{H}=0)$ is considered. All the field quantities are assumed to have the harmonic time dependence $\exp(-i\omega t)$. For the magnetic waves guided parallel to the x direction, a modal voltage and a modal current are rigorously defined and a transmission line model is developed. Explicit expressions for the inductance per unit length and the capacitance for unit length are obtained.

A unit cell of the magnetic film consists of a length ℓ_1 and of thickness $2a(1+t)$ cascaded to another magnetic film of length ℓ_2 and a thickness $2a(1-t)$. In the equivalent transmission line model, the matrix transferring the input voltage and current to the output voltage and current are obtained for this unit cell. Some useful properties of this matrix are obtained.

A magnetic film filter consists of N of the aforementioned unit cells in cascade joined on both sides to planar magnetic films of thickness 2a. The device is assumed to be symmetrical with respect to the midplane $z=0$. For a magnetic film filter consisting of $N=25$ unit cells, the spectral characteristics of the power reflection coefficient is obtained to display the frequency selective filter action of the device. For small values of the relative corrugation depth t, the results are compared with those of J. P. Parekh and H. S. Tuan [IEEE Trans. Microwave Theory Tech., MTT-26, 1039(1978)] who use a perturbative method.

For the maximum power reflection coefficient and the center frequency for which this maximum power reflection is obtained, the results of the perturbation theory are compared with those of the present theory which is applicable to large values of the relative corrugation depth. Some comments on the range of validity of the perturbation theories, and techniques for improving the present transmission line model are given.

A COMPARISON OF THE PROPERTIES OF THREE TRANSMISSION LINES AT LOW FREQUENCIES

R.D. Nevels, J.E. Wheeler and H. Weigel
Department of Electrical Engineering
Texas A&M University
College Station, Texas

Electric power needs on the new American space station will be served by solar panels that are to be located near the center of space station frame and which distribute power through cables connected to living and working quarters. Until recently no decision had been made concerning a power transmission frequency, which could be anywhere in the range 0-20KHz, and whether the power would be distributed by a one, two or three phase system. Also the transmission line must satisfy the requirement that it be low loss, easily connected at termination and possibly exposed to the space environment. In this paper we present a study of three alternative transmission line cable systems. These are: the coaxial line, the two wire line in a dielectric cylinder with a conducting shield and a two-wire line in a dielectric cylinder with an exterior infinite plasma region.

Analytical expressions for the resistance (R), inductance (L), conductance (G) and capacitance (C) per unit length have been derived at DC and at high frequency, but except for the coaxial line are not available in the lower frequency range. Our solution is based on an analytical-numerical technique whereby Green's functions are derived and integral equations are obtained in terms of the charge on the conducting surfaces. The Method of Moments numerical techniques is used to solve for the surface charge. Once the charge is found the electromagnetic fields and therefore the R,L, G and C parameters can be calculated. Results are presented in terms of line parameters R, L, G and C, the power loss and the voltage drop per meter on each line.

PHILA. NORTH
B-16—MICROSTRIP AND ANTENNAS
Chairman: N.G. Alexopoulos
THURSDAY-AM

STATIC CAPACITANCE OF A SMALL MICROSTRIP PATCH OF ARBITRARY SHAPE

Edward F. Kuester
Electromagnetics Laboratory
Department of Electrical and Computer Engineering
Campus Box 425
University of Colorado
Boulder, Colorado 80309

At the January, 1986 National Radio Science Meeting in Boulder, the author presented an explicit, closed-form approximation for the static capacitance of a microstrip patch of arbitrary shape, whose diameter and other patch dimensions are large compared to a substrate thickness. In this paper, we present a similar closed-form approximation for the case when the patch diameter is small compared with substrate thickness. Such small and medium sized patches are used as lumped network elements in microstrip circuits, and thus closed-form expressions for their capacitance should be useful for design. Taken together, the formulas for large and small patches have been found to provide estimates of the capacitance of any patch within 10% or less.

The approximation is obtained using a method suggested by Kolybel'nikova and Simonenko (Izv. VUZ Elektromekhanika, no. 7, 720-724, 1971) who did not, however, address the microstrip configuration specifically. We formulate an integral equation for the charge distribution on the strip, and note that the Green's function kernel of this equation is a constant times the free-space Green's function, plus a smaller perturbation term which is approximately constant. Using standard perturbation methods, we can obtain our approximation in terms of the capacitance C_∞ of the same patch isolated in free space, and the permittivity and thickness of the substrate. Some sample numerical results will be presented.

AN EFFICIENT APPROACH FOR EVALUATING THE PLANAR MICROSTRIP GREEN'S FUNCTION

Sina Barkeshli and P.H. Pathak

The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

An efficient approach is developed for evaluating the planar microstrip Green's function which essentially represents the field of an electric current point source on a grounded dielectric slab, when the source and observation points are located at the dielectric air interface. This surface Green's function is essential for determining the currents on arbitrarily shaped microstrip antenna elements when employing a Moment Method (MM) solution of the integral equation for these currents. Previous work has in most cases employed either the Sommerfeld type integral,or a plane wave spectral representation for this microstrip Green's function. Although different techniques have been proposed to improve the efficiency of numerical evaluation of these integrals with oscillatory integrands, almost all of these approaches employ integration along a contour which does not provide a rapid convergence with lateral (rather than vertical) separation of the source and field points.

In the present work, a transformation of the Sommerfeld integral is appropriately introduced in the complex plane so that the new representation exhibits a rapid convergence with lateral separation of source and field points due to an exponential decay in the integrand. Furthermore, if the lateral separation becomes reasonably large , a closed form uniform asymptotic representation of this integral can be used. These properties of the present solution make it efficient for dealing not only with the radiation/scattering associated with a single microstrip element, but also with microstrip arrays where efficiency becomes a crucial factor in numerical computations.

Examples illustrating the efficiency and the accuracy of the present approach will be illustrated through numerical MM calculations of self and mutual impedances in microstrip arrays.

AN ASYMPTOTIC EXTRACTION TECHNIQUE FOR THE REAL-SPACE EVALUATION OF SOMMERFELD-TYPE INTEGRALS

David R. Jackson
Electrical Engineering Department
University of Houston-University Park
Houston, TX 77004

N.G. Alexopoulos
Electrical Engineering Department
University of California, Los Angeles
Los Angeles, CA 90024

In the analysis of printed circuit antennas, one of the most time-consuming steps is usually the evaluation of Sommerfeld-type integrals. In the spectral-domain approach, the integral expression for the reaction between two basis functions of current converges for all observation and source heights z, z' above the ground plane, but convergence becomes worse as the basis function size becomes smaller, and the separation in x,y becomes larger. This difficulty can be partially overcome by using an extraction technique in the spectral domain (D.M. Pozar, Electromagnetics, vol. 3, no. 3-4, pp. 299-309, July-Dec., 1983). In this presentation an extraction technique in the real-space domain will be developed.

The starting point will be the Sommerfeld expressions for the magnetic vector potential. By extracting asymptotic terms which are dependent on z and z', a rapidly convergent expression for the electric field due to a Hertzian dipole will be derived. This expression has the advantage of being convergent for all z and z'. Also, because the expression is in the real-space domain the reaction between electrically small basis functions may be easily computed, even for large separations between the basis functions. This makes the technique very useful for computing the mutual impedance between printed dipoles when using the method of moments. After the technique is developed, results for mutual impedance obtained in this way will be presented. The effect of the substrate material and dipole orientation on the electric field of the Hertzian dipole will also be discussed.

AN ASYMPTOTIC EVALUATION OF THE MUTUAL COUPLING BETWEEN TWO MICROSTRIP PATCH MODES ON A DIELECTRIC COATED CIRCULAR CYLINDER

B. W. Kwan
The Florida State University
Department of Electrical Engineering
102 Education Building
Tallahassee, FL 32306

A crucial step in the moment method solution of an integral equation for the current distribution on an array of microstrip antennas on a dielectric coated cylinder is the evaluation of the mutual impedance between the microstrip patch modes. The mutual impedance between two microstrip patch modes on a dielectric coated cylinder can be expanded in terms of the eigenfunctions associated with the coated cylinder. The expansion is obtained using the radially propagating dyadic Green's function. Typically, the eigenfunction expansion is poorly convergent when the coated cylinder is large compared to a wavelength. For large cylinders asymptotic high frequency solutions are desirable because they are much more efficient computationally, and can be conveniently interpreted in terms of ray-optics.

In this paper, the mutual coupling between two microstrip patch modes has been considered for the case of an electrically large coated cylinder. An essential step in deriving the asymptotic solution is the conversion of the radially propagating Green's dyadic function, (upon which the rigorous eigenfunction solution is based), into a circumferentially propagating Green's function. This is done via the employment of the Poisson summation formula. Thereby two alternative expressions for the mutual impedance between two microstrip patch modes are obtained. The first one is an integral representation which is derived by replacing the cylinder functions by their Debye approximations, and is valid when the two patch modes are close to each other. The second one is the residue series representation resulted from replacing the cylinder functions by the Airy functions and then applying residue calculus. The residue series is suitable when the patches are separated by no less than a wavelength. Numerical results are presented and compared to the rigorous eigenfunction solutions.

STUDY OF THE MICROSTRIP LINE FEED AS AN INTEGRAL PART OF THE MICROSTRIP ANTENNA

M. Davidovitz and Y. T. Lo
Department of Electrical & Computer Engineering
University of Illinois
Urbana, Illinois 61801

In order to facilitate the analysis of various microstrip antenna problems, the feeding structures have been in most cases simplified by replacing the actual feed by an idealized current probe or ribbon. Such models have been shown to be adequate for calculating the input impedance of the microstrip antennas when the substrate thickness is small compared to the wavelength. However, as the substrate thickness increases, the actual feeding structure has to be taken into account in order to obtain accurate values of input impedance.

This paper considers the case of the circular microstrip patch first with a probe feed and second with a microstrip line feed. The integral equations for the currents on the patch and the feed line are formulated in the Fourier domain. Moment method solution is implemented by expanding the current in full-domain basis functions on the circular patch and subsectional basis functions on the microstrip feed line. The resulting moment method matrix elements are expressed as improper integrals over the transform domain. Particular attention is given to improving the convergence of these integrals, resulting in substantial saving in computational efforts. Finally, all computed input impedance data are compared with experimental results.

THE MICROSTRIP ANTENNA WITH FINITE GROUND PLANE FOR USE WITH SATELLITE POSITIONING SYSTEMS

J. M. TRANQUILLA AND B. G. COLPITTS
DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF NEW BRUNSWICK
FREDERICTON, NB, CANADA

SUMMARY

In the use of satellite positioning systems such as the Global Positioning System (GPS) significant errors can be introduced into the indicated position through the properties of the antenna structure. Of particular interest are the phase characteristics of the antenna as a function of observation angle. The microstrip antenna features a rugged, low profile and light weight construction making it an ideal choice for practical applications, but positioning accuracy may be limited by the mounting surface.

The rectangular microstrip antenna is investigated using slot theory and the Uniform Theory of Diffraction (UTD) for its applicability in GPS applications. Amplitude,phase and phase centre characteristics are studied with particular emphasis on the pattern response at low elevation angles which are of particular interest in hydrographic and aviation applications.

Analytic and experimental data are presented to show the effects of groundplane size and the use of electrically lossy material in producing a suitable amplitude and phase response.

BACKSIDE RADIATION FROM A MICROSTRIP PATCH ANTENNA

Juan R. Mosig and Fred E. Gardiol

Laboratoire d'Electromagnétisme et d'Acoustique
Ecole Polytechniqùe Fédérale de Lausanne
Ch. de Bellerive 16, CH-1007 LAUSANNE, Switzerland

The radiation pattern of a microstrip patch antenna is usually calculated by assuming a ground plane having infinite transverse dimensions. The situation is quite different in practice, where many ground planes have dimensions not exceeding a few wavelengths. Hence, the theoretical predictions deviate considerably from experimental results for grazing angles and fail completely at the rear of the antenna.

This communication presents a first-order correction, to predict correctly the side lobes and the radiation level on the back side of the antenna.

In a first step, the microstrip patch is analyzed by assuming an infinite ground plane. An integral equation technique combined with a method of moments is used to evaluate the electric surface current on the patch (Mosig & Gardiol, IEE Proc. Part-H, Dec. 1985).

This current is used as the source in a second problem, in which the finite ground plane acts as a scatterer. It is worth mentioning here that the Green's function for this problem does not include the ground plane and requires a finite substrate. On the other hand, the dielectric substrate can still be considered as having infinite transverse dimensions, in which case the modified Gree's function suffices as a first approximation.

A physical-optics solution for the electric current induced in the ground plane gives a first-order correction to the radiation pattern, useful at wide angles to predict the sidelobe levels. To evaluate the backside radiation, it is necessary to consider again an integral equation whose unknown is now the electric surface current on the ground. Superposition of the fields radiated by both currents on the patch and on the finite ground plane provides an estimation of the fractional power radiated back.

SCATTERING FROM A MICROSTRIP PATCH

E. H. Newman
Ohio State University
Dept. of Electrical Engr.
Columbus, OH 43212

E. H. Y. Yeh
Code 3313
Naval Weapons Center
China Lake, CA 93555

This paper will describe an integral equation and method of moments (MM) solution to the problem of plane wave scattering by a rectangular microstrip patch on a grounded dielectric slab. Microstrip patches can have significant scattering near a series of frequencies corresponding to the patch resonances.

The first step in obtaining the integral equation is to use the surface equivalence principle to replace the perfectly conducting patch by an equivalent surface current density. This current radiates the scattered field in the presence of the grounded dielectric slab. The integral equation is then obtained by requiring that the total electric field tangential to the patch vanish. The total electric field is the sum of the incident plus the scattered fields.

The integral equation is solved by the MM. In the MM solution, the unknown current is expressed as the sum of N expansion modes. Next, N weighted averages (or moments) of the integral equations are required to be true. The result is that the integral equation is transformed into an N x N system of simultaneous linear equations. These equations are then solved for the N coefficients in the original expansion for the current. We employed entire domain Fourier type expansion and weighting modes.

Previous MM solutions for microstrips have emphasized the antenna or radiation problem, where the primary interest is in a narrow band of frequencies near first resonance (where the patch length is about a half-wavelength in the substrate material). By contrast, in the scattering problem, we are interested in a very broad range of frequencies, starting from where the patch is small in terms of a wavelength to where it may be several wavelengths in length. The result is that the computer time to compute the scattering over a broad frequency range can easily become prohibitive. Method for significantly reducing the computer run time will be discussed.

SALON 3/4
B-17—BEAMS AND SCATTERING
Chairman: S.W. Lee
THURSDAY-AM

GAUSSIAN BEAMS AS A NEAR-FIELD MODEL OF APERTURE SOURCES IN LOSSY MEDIA

J. Bach Andersen, E. Gross, M.L.D. Lumori
Department of Radiation Oncology, University of Arizona
Tucson, Arizona 85724

When simulating the heating process in tissue for hyperthermia treatment of cancer, there is a need for a simple, yet accurate description of the field distribution from aperture antennas. Knowledge of the fields is needed from close to the aperture to some distance into the tissue limited by the absorption decay. Thus, ordinary far-field calculations are of no interest, since the fields are vanishingly small when the approximations are good. Alternatively, exact aperture integrations may be performed but they are very time-consuming, since we want the power density at closely spaced points in three-dimensional space. This is needed as input data for a temperature evaluation; there is also a need for rapid calculations for phased-array studies.

The general Gaussian astigmatic beam in the paraxial approximation is studied as a possible model for the cases mentioned, since it has the necessary simplicity which makes it not only easy to calculate but also to infer simple results about the penetration depth vs. aperture size, etc., and it is possible to describe the fields from a distance very close to the aperture.

The basic assumptions are that 1) a Gaussian function is able to describe the transverse variations of the fields in the aperture and 2) longitudinal variations are faster than transverse ones. In lossless media, the first assumption is not satisfied very well for ordinary waveguide aperture illuminations, but the losses rapidly smooth out the sharp transitions improving the model. Similarly, the losses will tend to improve the second assumption as well, so that it is valid even for relatively small apertures which only contain a single mode.

The main problem for the present application is the medium inhomogeneity, but it is felt that a good model for the homogeneous case is important since it may serve as a starting point for analytical or numerical treatment of the inhomogeneous case.

In the presentation, the Gaussian model will be compared with numerical and experimental results relating to propagation in muscle tissue. Preliminary results show that the theory explains the additional decay due to finite aperture size.

HIGH FREQUENCY BEAM DIFFRACTION BY STRIP REFLECTORS

G.A. Suedan and E.V. Jull
Department of Electrical Engineering
University of British Columbia
Vancouver, B.C. Canada V6T 1W5

Most antenna beams are well represented by a Gaussian function. An isotropic point or line source with a complex position coordinate yields a beam Gaussian in a paraxial region (G.A. Deschamps, Elect. Lett. 7, 684, 1971). This provides a simple and powerful method of including source directivity in antenna diffraction analysis. With the complex source point method a solution for an isotropic source is converted to that for a beam by simply making one or more source coordinates complex. The method is particularly advantageous in high frequency diffraction where numerical methods encounter difficulty. Some simple numerical examples are given here.

An electric dipole parallel to a plane conducting strip is the simplest of reflector antennas. In its analysis a canonical solution is the exact far field of an electric line source parallel and near to the edge of a conducting half plane, an expression in terms of Fresnel integrals. Two such solutions ,appropriately added, constitute an accurate result for the H plane pattern of the reflector antenna. Interaction fields of the strip edges are negligible for strip widths larger than about 0.7 wavelengths. Retaining the Fresnel integrals ensures there are no shadow boundary singularities.

By making the source height above the strip complex the incident field becomes a directive beam. The beam width is approximately inversely proportional to the square root of the imaginary part of the height coordinate. Thus the pattern of a directive line source, for example a waveguide array of uniformly excited slots in front of the reflector, can be calculated. The numerical results show the evolution of the radiation pattern from an isotropic source to a highly directive beam for which the edges of the reflector have no effect on the pattern.

A natural extension of this is to a parabolic cylinder reflector. Beam diffraction by a paraboloidal surface without edges has already been described (Hasselman and Felsen, AP-30,677-685, 1982). Here first order edge diffraction will also be considered.

EDGE DIFFRACTION OF FIELDS IN CAUSTIC OR CUSP REGIONS: GAUSSIAN BEAM APPROACH

S.Calderone, I.Montrosset, M.Orefice, R.Tascone
Centro Studi Propagazione e Antenne del CNR,
Dipartimento di Elettronica, Politecnico di Torino
C.Duca degli Abruzzi 24, 10129 Torino, Italy

Particular attention has been recently devoted to extend the validity of Geometrical Optics (GO) in regions where this method leads to field singularities, by using complex rays or field expansion in terms of Gaussian Beams (GBs). In this communication, following the approach recently proposed by some of the present authors (J.Opt.Soc.Am. - A, April 1986) for the expansion of a general field in terms of GBs, the diffraction of an incident field with caustics or cusps will be considered. These conditions are commonly found in guiding ducts or in multireflector antenna systems.

The key steps of the numerical procedure proposed here are the following:

- the incident field is expanded in terms of collimated GBs or Complex Source Points (CSP);
- the UTD diffraction coefficients for incident GB fields are obtained by analytical continuation of real distances and angles to complex space.

The sum of direct, reflected and diffracted fields produced by each constituent GB gives the total field, which is regular also in the singularity regions of the GO field.

In order to verify the validity of the procedure some examples have been considered: firstly, the case of a parabolic cylinder with off focus line source has been analyzed; this is the typical example providing both reflection caustics and diffraction. Physical optics results has been assumed as the reference solution.

Edge diffraction from a focused field, which may be obtained by means of a reflector or a lens, has also been considered. Depending on the position, the edge may scatter fields in a cusp or caustic region, and the behaviour of the diffracted field in the different configurations has been examined.

HERMITE-GAUSSIAN BEAMS AS BUNDLE OF COMPLEX RAYS

K. M. Luk
Department of Electronic Engineering
City Polytechnic of Hong Kong
700 Nathan Road, Mongkok,
Hong Kong

Mathematically, by assigning complex values to the source coordinates in the field expression of an electric or magnetic oscillating point multipole, a fundamental Gaussian beam wave formula is obtained. This complex-source-point technique has been applied for the high frequency asymptotic treatment of the propagation and scattering of the fundamental Gaussian beam, e.g. (Gao and Felsen, IEEE Trans. Ant. Prop., 33, 963-975, 1985). A more general treatment of the beam-wave scattering can be initiated provided we can generalize the complex-source-point technique to include the higher-order Gaussian beams. The objective of this paper is to handle this problem. It is shown that by locating a multipole line(point) source of order m(m+n+1) at a complex location, a two-(three-) dimensional Hermite-Gaussian beam is generated.

AN ASYMPTOTIC SOLUTION FOR CURRENTS IN THE PENUMBRA REGION WITH DISCONTINUITY IN CURVATURE

C. W. Chuang
The Ohio State University ElectroScience Laboratory
Department of Electrical Engineering
Columbus, Ohio 43212

In an early study, Hong and Weston (Radio Sci., 1, 1045-1053, 1966) obtained a modified Fock function to describe the current distribution induced by a high frequency plane wave incident upon a conducting surface composed of a flat plate smoothly joined to a parabolic cylinder with the join in the penumbra region. Their work is an extension of the Fock theory (J. Phys., 10, 130-136, 1946) which deals with the current distribution induced on a parabolic convex surface. The modified Fock function as described by Hong and Weston is computed using an analytical method when $ka\alpha^3$ is negligible, where k is the wave number, a is the radius of curvature of the parabola at the join and α is the angle of incidence measured from the flat plate. However, when $ka\alpha^3$ is moderately large (in the order of unity), the modified Fock function is computed using a numerical method. It is the purpose of this paper to present an analytical asymptotic result for the modified Fock function applicable even for large $ka\alpha^3$. This analytical result can be conveniently applied to estimating the backscattering cross section of a cone-sphere.

RADAR CROSS SECTION PREDICTION FOR COATED PERFECT CONDUCTORS WITH ARBITRARY GEOMETRIES

S. W. Rogers and R. T. Shin
Department of Electrical Engineering and Computer Science
and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Mass. 02139

Radar cross section predictions for coated objects is an important problem with many practical applications. The method of moments is applied to solve the electromagnetic scattering from a dielectric/magnetic coated perfect conductors with arbitrary geometries. The governing equations are derived by making use of the equivalence principle and the dyadic formulation of Huygens' principle. Matching boundary conditions then generates a set of integro-differential equations with the equivalent electric and magnetic surface currents as the desired unknowns. Triangular patch modelling is applied to the boundary surfaces. The method of moments with a bi-triangular subdomain basis is used to convert the integro-differential equations into a matrix equation which can be solved by matrix inversion for the unknown surface current coefficients. Huygens' principle is again applied to calculate the scattered electric field produced by the equivalent surface currents. Finally, the far-field monostatic radar cross section is calculated from the scattered electric field. Radar cross section measurements of various coated and uncoated objects also have been made to validate the theoretical predictions. Comparisons between the predicted and measured data are made and the result of detailed investigation of scattering behavior will be discussed to provide insight into critical target element interactions.

RADAR SCATTERING BY METALLIC BODIES OF REVOLUTION
WITH OR WITHOUT RESISTIVE COATING

James Joseph and Raj Mittra
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

In this paper we present the results of the investigation of the problem of radar scattering by a metallic body of revolution, which may be coated with an arbitrarily-graded, resistive material that is employed to reduce the radar cross-section of the target. The study is of interest in the design of several different types of airborne targets, including airplanes whose engine inlets often produce substantial scattering of an impinging radar signal.

The problem of plane wave scattering from a body of revolution has been studied in the past (A. W. Glisson and D. R. Wilton, T-AP, 28, 593-603, 1980). However, the reduction of radar cross-section resulting from the impedance boundary condition, introduced on the surface of the scatterer by the resistive coating, has not been investigated. In this paper, we address this problem by formulating an electric field integral equation for the surface current J, by enforcing the Leontovich (impedance) boundary condition on the surface of the scatterer. It is shown that the use of the entire domain basis functions reduces the matrix size considerably, typically by a factor of three. However, this also introduces certain artifacts in the solution for the surface current that are non-existent when the subdomain basis functions are used instead. Some approaches to eliminating these artifacts, and circumventing the convergence problem that arise with the use of entire domain basis functions are discussed in the paper.

As an illustrative numerical example, the current distribution on an open-ended cylinder is shown in Fig. 1, for both the PEC and the resistively-coated cases. Other examples are also included in the paper.

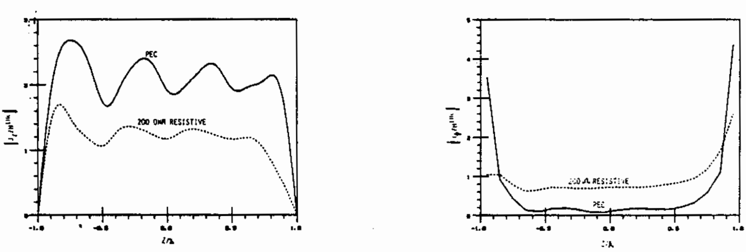


Figure 1. Surface current distributions on an open-ended cylinder of ka = 1.0, kL = 4π, illuminated by an axially incident plane wave traveling along negative z direction.

MODAL ATTENUATION IN AN OVERMODED DIELECTRIC-COATED CIRCULAR WAVEGUIDE FOR RCS REDUCTION

R. Chou, C. S. Lee and S. W. Lee
Electromagnetics Laboratory
University of Illinois
Urbana, Illinois 61801

The radar cross section (RCS) of a circular waveguide terminated by a perfect electric conductor has been studied extensively because it can model many practical devices such as the jet intake of an airplane, missile, etc. It is known that the RCS can be significantly reduced if the PEC-terminated waveguide is coated with a lossy magnetic material and the frequency is low ($a/\lambda \leq 1$, a = radius of the waveguide and λ = the free-space wavelength). But in many applications, the dimensions of the device are much larger than the wavelength, and the low-order modes (which are mostly responsible for the RCS near axial incidence in an overmoded waveguide coated with a lossy material) have small attenuation constants which decrease as a function of λ^2/a^3. Consequently, the RCS reduction of a waveguide coated with a single lossy layer is limited to small ranges of frequency and incident angle.

The purpose of this paper is to demonstrate that with a double layer of coating, the low-order modes can have very large attenuation constants over a broad range of frequency, even if the coating material is very lossy and the coating layer is thin. And, a larger RCS reduction is possible over a wider range of frequency and incident angle than in the single layer coating case.

With a double-layer of coating, the fields inside the waveguide can be more easily manipulated than with a single-layer. We have found that a lossy layer usually expels the fields as the frequency increases, and the attenuation constants become small. A lossless coating with high permeability or permittivity, however, attracts fields in an overmoded waveguide, but no attenuation is attained. Thus it is difficult to get high attenuation constants of the normal modes using a single layer of coating when a/λ is large. On the other hand, a double layer of coating with a lossless layer near the waveguide wall and a lossy and magnetic layer towards the center of the cylinder results in large attenuation constants of the low-order normal modes over a broad range of a/λ value. With application of this technique, it is possible to obtain large RCS reductions for a broad range of practical problems.

RADAR CROSS SECTION PREDICTION USING A HYBRID METHOD

C. F. Lee and R. T. Shin
Department of Electrical Engineering and Computer Science
and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Mass. 02139

The method of moments (MoM) is widely used to calculate the radar cross sections of arbitrarily-shaped objects. However, its application is limited to small objects due to large computation time required. A hybrid method which combines the MoM with the physical theory of diffraction (PTD) may be used to speed up the computation time and extend the applicability of MoM to electrically large objects. In the hybrid method, rather than directly inverting the impedance matrix, one uses an iterative method to solve for the induced surface current with the approximate surface currents obtained using PTD. For flat plates, the physical optics and the edge diffraction currents are used. For cylindrical objects, physical optics current, creeping wave current, and approximate expression for the transition region current are used. The region over which MoM is applied may be the whole object or it may be limited to the regions where the PTD currents are not accurate. Iteration methods such as conjugate gradient and successive over-relaxation are used. It is shown that by using the approximate PTD currents, the iteration converges faster. Also, when calculating the RCS as a function of incident angle, it is shown that the iteration converges very fast if the current calculated for the previous angle of incidence is used as an initial guess. The convergence is even faster if the initial guess for the phase of the current is modified by the differences in the phases of the physical optics currents for the two angles of incidence. The theoretical results will be illustrated by calculating radar cross sections of large objects where conventional MoM cannot be applied and comparing with experimental data.

SALON 5/6
B-18—ELECTROMAGNETIC THEORY II
Chairman: R.J. King
THURSDAY-AM

THE APPLICATION OF GROUP THEORY TO ARRAYS

Haralambos N. Kritikos
James E. Richie
Department of Electrical Engineering
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Pa.

Abstract group concepts can provide useful insight into the study of various electromagnetic applications involving symmetry, such as antenna arrays. The application of group theory to array geometries, however, has not been investigated.

Group theory has been extensively used in quantum mechanics to solve Shrodinger's equation. In solid state physics, energy band calculations for crystalline solids heavily depends on the point group symmetry of the crystal lattice.

In this paper, the point groups will be studied in the context of antenna arrays. Each group exhibits a character table which contains the irreducible representations of the elements of the group. The character table also admits a set of basis functions for the irreducible representations, which are orthogonal by the great orthogonality theorem. In summary, the character table contains all the information necessary to completely specify all the properties of a group.

The field pattern of each orthornormal basis function from a group can be calculated. The relative merits of each array geometry will be discussed by comparing the field patterns associated with each group.

DIFFRACTION OF PLANE WAVES PAST A SERIES OF ABSORBING HALF-SCREENS

Joram Walfisch and Henry L. Bertoni
Center for Advanced Technology in Telecommunications
Polytechnic Institute of New York
Brooklyn, N.Y. 11201

In modeling UHF/microwave propagation in Urban environments, rows or blocks of buildings of nearly uniform height are replaced by parallel absorbing half-screens, whose separation is large compared to wavelength. Propagation is then veiwed as a process of multiple diffraction past a series of half-screens. Even though the buildings have irregularities on the order of the wavelength, the forward diffracted field retains phase coherence with the incident field. However, the back diffracted fields lose phase coherence, and are neglected.

This paper describes the computation of the fields resulting when a plane wave is diffracted by a series of absorbing half-screens whose edges are of uniform height. In our studies diffraction by as many as 130 half-screens has been considered. A Kirchhoff-Huygens integration is used to find the field in the plane of one half-screen due to the field propagating past the plane of the previous half-screen, and the process is repeated in sequence for all screens. Choice of the integration rule, integration step size, integration aperture size and truncation strategy are discussed.

The field incident on the edge of the Nth half-screen is computed as a function of N. For a given finite glacing angle α, the field is found to settle to a limit value for N large enough. When $\alpha$is small, the settled value is found to vary as α to the 0.9 power. For α=0, the field at the edges is found to vary as $1/\sqrt{N}$. Transverse variation of the settled field in the plane of the half-screen is found and interpreted in terms of simple refraction and diffraction processes.

CALCULATION OF THE SURFACE FIELD AT AN INTERIOR RESONANCE POINT

R.K.Ritt, Illinois State University, Normal IL 61761

It is known that many scattering problems, when represented as an integral equation on the surface of a bounded scatterer, can be characterized by the equation:

$$M(k)x(k) = y(k).$$

$x(k)$ is the unknown surface field, $y(k)$ is a known source field (at the surface), and $M(k)$ is a known linear operator. It is further known that $y(k)$ and $M(k)$ are analytic for all k, and that $M^{-1}(k)$ is meromorphic whose real singularities occur at those values of k which correspond to interior resonances of the scatterer. It is also known that if $k=k_o$ is such a singularity, $x(k)$ has a removable singularity at $k=k_o$. However, the value of the surface field

$$x_o = \lim_{k \to k_o} x(k) = \lim_{k \to k_o} M^{-1}(k)y(k)$$

is ,in general, not easily calculated, because of the poor conditioning of the matrix approximation for $M(k)$ for values of k close to k_o.

We shall show that the problem of calculating x_o can be reduced to the problem of inversion of a nonsingular operator, and that no limits need be calculated.

For example, suppose $M^{-1}(k)$ has a pole of order one at $k=k_o$, and $M(k)$ and $y(k)$ have the Taylor expansions:

$$M(k) = M_o + (k-k_o)M_1 +\dots ; \; y(k) = y_o + (k-k_o)y_1 + \dots .$$

Then if Z_o is the projection on the null space of the adjoint of M_o, and $X_o = I - Z_o$, then the operator

$$M_{o,1} = X_oM_o + Z_oM_1$$

is invertible, and

$$x_o = M_{o,1}{}^{-1} (y_o + Z_oy_1) .$$

In general, it is possible to find the form of the appropriate invertible operator without <u>a priori</u> knowledge of the order of the pole of $M^{-1}(k)$. However, in this case, it is required, at each stage of a recursive process, to test the operator which is obtained,for invertibility. The process terminates at that step corresponding to the order of the pole of M^{-1} (k).

APPROXIMATE ANALYTIC CONTINUATION OF THE RAYLEIGH SERIES BEYOND ITS RADIUS OF CONVERGENCE

Donald C. Power
Raytheon Company
Missile Systems Division
Hartwell Road
Bedford, Ma 01730

Pade approximants are used to approximately continue the Rayleigh series for the radar cross section of the sphere beyond its radius of convergence. Numerical studies show that accurate results for the RCS can be obtained to $ka \approx 2.2$ if many series terms are available. Since this is rarely, if ever, the case, it is further demonstrated that even with as few as four non-vanishing terms available, the technique is accurate to $ka \approx 1.3$. This provides an indication of the number of series terms which must be calculated in order to use the Rayleigh series in the lower part of the resonance regime. An additional point that is demonstrated is the ability of the technique to provide highly accurate estimates of the radius of convergence of the series.

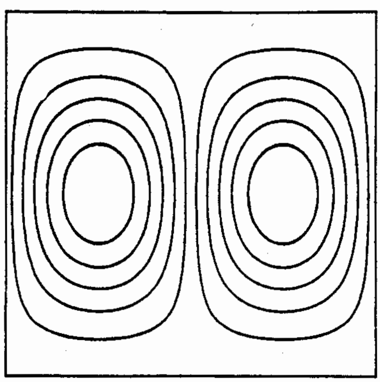
COMPUTER PROGRAM FOR PLOTTING THE VECTOR FIELDS

Darko Kajfez and R. Todd Ward
Department of Electrical Engineering
University of Mississippi
University, MS 38677

Plotting of electromagnetic fields by computer typically requires writing a program for each individual situation. While there are computer programs available for plotting the scalar fields, like in SAS package, there are no general-usage programs for plotting the vector fields. An attempt in creating such a program will be described here.

The input data for the program consist of table of values of the field to be plotted, specified at equidistant points. These values can be, for instance, the x and y components of the electric field, or of any other vector field. The program is written in Fortran language, and it makes use of the PLOT 10 graphics package. As a first step in the interactive procedure, the vector field is displayed in a form of local arrows, in order to enable the user to find a symmetry axis of the field. The user then specifies the end points of the symmetry axis and determines how many field lines are to be plotted. The program divides the total vector flux across the symmetry axis into specified number of partial fluxes. In this way, the starting points of each field line are found. The lines are drawn in small increments, using a simple two-step procedure reminding of Runge-Kutta procedure. The illustration shown below depicts a modal field in the rectangular waveguide, plotted from the data consisting of 16 by 16 points.

This material is based upon work supported by the National Science Foundation under Grant ECS-8443558.



A TIME-DOMAIN SEM VIEW OF COUPLING COEFFICIENTS

William A. Davis, Virginia Poly Inst and State University, Blacksburg, VA, and Douglas J. Riley, Sandia National Labs, Albuquerque, NM

Since the mid-1970's, concern about coupling coefficients in the singularity expansion method (SEM) has been of interest to a number of researchers. A thorough discussion based on standard complex frequency domain approaches to SEM has been presented by Baum and Pearson [Electromagnetics, 1:2, 209, 1981).They found the coefficients could be defined by a number of classes which are equivalent analytically, but with possibly varying effects numerically. The latter is particularly true toward efficiency of the technique applied. This paper explores these questions for the time-domain approach to SEM computation.

This time-domain approach depends on solving the a transient difference equation for the poles of the scatterer. The particular difference form is identical to the phase canonical form found in control theory for multiple input-output relations. Once the poles are known, the coupling coefficients may be obtained in an analogous manner to the frequency-domain approach. However, these coefficients become difference type, time convolutions, and take various forms depending on the particular expansion of the incident field during illumination. This is precisely the conclusion reached in the frequency-domain form from which one concludes analytic equivalence of the various classes of coefficients.

This paper will consider the simplest manner for developing the coupling coefficients in the time-domain with the resultant class-2 form. Variations also will be presented to gain insight into the other classes as obtained from a transient approach.

NEW METHODS FOR QUANTIFICATION OF INDUCED EM FIELDS IN FINITE HETEROGENOUS BODIES

H. Wang and K.M. Chen
Department of Electrical Engineering and Systems Science
Michigan State University, E. Lansing, MI 48824

Some new methods to improve the numerical solution for the induced EM field in a finite body are investigated.

For the first method, we have modified the tensor integral equation method developed by Liversay and Chen with an equivalent magnetic surface current to improve accuracy of numerical results. In the numerical solution of the tensor integral equation, the pulse basis function expansion creates the discontinuity of E field at the boundary of adjacent cells. An equivalent magnetic surface current is introduced to compensate the discontinuity of the tangential component of E field at the boundary.

The second method uses an iterative loop-EMF method which is designed to calculate the E field of the magnetic mode induced by the incident magnetic field. Faraday's law is applied to each subdivided cell to relate EMF of the cell to the magnetic flux linkage. The system of linear equations for EMF's can be solved in terms of the H field in each cell. To start the iterative process, we use the incident magnetic field as the zeroth-order H field to solve for the zeroth-order EMF. From this EMF and the resulting induced current the first-order H field can be calculated. After that the first-order EMF can be determined. The iteration continues until both EMF and the H field converge.

Another new method utilizes the linear type functions of Serendipity family as the basis function to solve electric field integral equation. The advantage of this method is that it guarantees the continuity of the E field, in both normal and tangential components, between adjacent homogeneous cells.

ASSESSMENT OF THE ABILITY OF BLOOD FLOW TO REMOVE HEAT FROM TISSUE IRRADIATED BY RADIOFREQUENCY ELECTROMAGNETIC RADIATION

Shu Chen Li
Department of Mathematics
Trenton State College
Trenton, New Jersey 08625

D. K. Cohoon
Department of Mathematics
Temple University 03816
Philadelphia, Pennsylvania 19122

Using concepts of Cohoon and Burr (SAM-TR-82-2 of the USAF School of Aerospace Medicine in San Antonio, Texas 78235 and pp 452-560 of the IEEE Transactions on Biomedical Engineering, Volume BME-27, No. 8(1980)) we implemented in a computer program exact analytical formulas for the thermal response stimulated in a cylindrically symmetric layer of muscle surrounding a cylindrical column of blood by polarized time-harmonic, and planar electromagnetic waves with frequencies in the radiofrequency range. The surfaces separating the regions of homogeneity of the above structure are cylinders with circular cross sections whose axis is either parallel to the electric vector of the incoming wave(a transverse magnetic TM exposure) or is parallel to the magnetic vector of the incoming wave(a TE exposure). We first use cylindrical harmonics to express the solution of Maxwell's equations at any point in the interior of the structure, use Poyntings theorem to get a radiative energy transfer term Q_r at any point in the interior of the structure. Hilbert space methods are used to get a precise analytic solution of the equation,

$$\rho c\frac{\partial u}{\partial t} - \operatorname{div}(K(\operatorname{grad}(u))) = (1/2)(\sigma|\vec{E}|^2/(4.184\times10^6)),$$

where ρ, c, and K are, respectively, the tissue density, specific heat, and conductivity in c.g.s. and σ and $\vec{E}$ are the microwave conductivity and peak electric field strength, respectively in MKS units. We always assume that the blood is electromagnetically coupled to the simulated muscle material and that tangential components of the $\vec{E}$ and $\vec{H}$ vectors are continuous across the blood-muscle interface. However, by using different thermal coupling models we quantify the ability of blood to remove heat from irradiated tissue. Computer graphics were used to display the temperature increase u as a function of the radial coordinate for various times.

SCATTERING BY A CIRCULAR CYLINDER
WITH TRANSLATIONALLY INVARIANT ANISOTROPIES

N. J. Damaskos, H. Massoudi, J. C. Monzon
Damaskos, Inc., Concordville, PA 19331
and
P.L.E. Uslenghi
Department of Electrical Engineering and Computer Science
University of Illinois, Chicago, IL 60680

A circular cylinder of axis z and radius $\rho = b$ is made of a homogeneous lossy anisotropic material, and is surrounded by free space. With reference to principal axes (x_o, y_o, z), both permittivity and permeability tensors are diagonal. The incident field is a plane wave which propagates in a direction $\hat{x}$ perpendicular to the cylinder axis ($\hat{x} \neq \hat{x}_o$), and has arbitrary polarization. We want to determine the total field inside the biaxial cylinder and the scattered field in the surrounding free space.

The electromagnetic field inside the biaxial cylinder is the superposition of E-modes and H-modes, whose transversal components are obtained by first-order differentiation of the longitudinal components E_z, H_z. In turn, E_z and H_z are written as Fourier series whose terms are products of radial eigenfunctions and azimuthal exponential functions. The radial eigenfunctions satisfy differential-difference equations which become Bessel's equation when the cylinder's material is electrically and magnetically uniaxial.

The radial eigenfunctions may be written as finite integrals whose integrands are the products of known Bessel function, known exponentials, and an unknown function; thus, the problem is reducted to finding two unknown scalar functions of a single variable, one for E-modes and one for H-modes. Imposition of the boundary conditions at $\rho = b$ means that each of the two unknown functions satisfies a Fredholm integral equation of the first kind, whose solution is discussed numerically.

The technique used herein may be considered as a particular case of a more general approach to scattering by anisotropic cylinder, that is based on a plain-wave representation of the fields (J. C. Monzon and N. J. Damaskos, "Two-dimensional scattering by a homogeneous anisotropic rod", to be published).

SALON 10
B-19—INVERSE SCATTERING III
(Imaging and Signal Processing)

Chairman: A. Jordan

THURSDAY-AM

DISCRIMINATION OF SCATTERERS USING NATURAL RESONANCE ANNIHILATION

Michael A. Morgan
Electronics Division
Office of Naval Research
Arlington, VA 22217

James B. Dunavin
Air Force Institute of Technology
Dayton, OH 45433

The use of aspect-invariant complex natural resonances for identification of scatterers has been a topic of intense research for over a decade. In addition to the parameter extraction methods, such as that of Prony and its variants, a class of techniques has arisen which is based upon the annihilation of resonances in the received scattered signal. The "K-Pulse Concept" (Kennaugh, *IEEE Trans. AP-29,* 327-331, 1981) can be expanded to include a wide variety of convolutional filters for scatterer discrimination, as will be shown.

In this effort, various signal processing strategies are investigated for the extinction of the natural resonance energy which appears in the "late-time" (undriven) portion of an impulsively excited scattering response, (Morgan, *IEEE Trans. AP-32,* 466-473, 1984). Approaches considered include FFT synthesis of analog differential operator filters as well as directly implemented digital transverse convolution filters. Discrimination performance is tested for various levels of noise-pollution on scattering signals. These tests are performed for synthetically constructed signals as well as for transient scattered responses obtained by both numerical methods (integral equation) and time-domain measurements.

SUPER-RESOLVED TARGET RECOGNITION AND CLASSIFICATION BASED ON MODELS OF NEURAL NETWORKS

Nabil H. Farhat and Sunji Miyahara
University of Pennsylvania
The Moore School of Electrical Engineering
Electro-Optics and Microwave-Optics Laboratory
Philadelphia, PA 19104

Abstract

It is generally known that in performing arithmetic operations, the brain is not as efficient as a digital computer. But, when it comes to recognition and classification, it outperforms the most complex and powerful computer and does that with amazing speed and robustness (fault tolerance and reliable performance even when presented with partial or noisy inputs). In this paper we report for the first time on a new method for target recognition and classification based on known models of neural networks. We begin by reviewing the principles of *content addressable memory* (CAM) based on models of neural networks with iterative feedback and thresholding. The use of such CAM in the recognition of *sinogram classifiers*, representing the differential range profile of visible scattering centers of radar targets plotted against aspect angle will then be described. Results of numerical simulations in which a CAM was exercised that was "taught" sinogram classifiers of four random planar point test objects, representing the scattering centers of simplified radar targets, are presented. Correct recognition from partial versions of the stored entities that can be as low as a few percent is demonstrated. This is synonymous with the realization of super-resolution where a function is recovered from a noisy or imperfect part. An example of exercising the CAM is shown in Fig. 1. Finally the implications of the results for efficient and reliable radar target recognition and machine vision in general will be discussed.

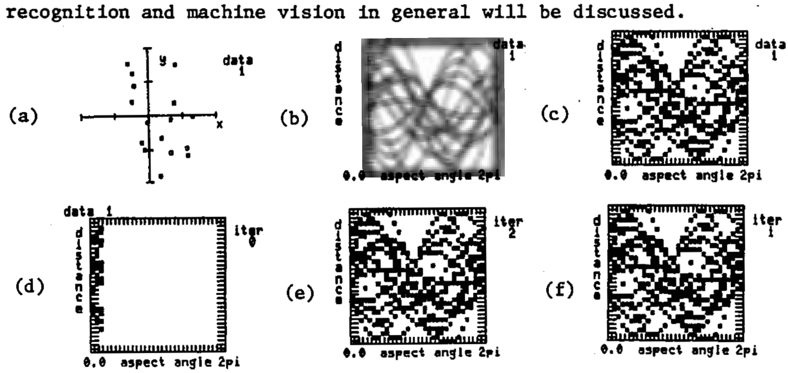


Fig. 1. (a) one of 4 test objects, (b) sinogram, (c) digitized binary sinogram, (d) partial version of (c) used to prompt CAM, (e) CAM output after one iteration and (f) after two iterations yields complete entity.

PHASE GRADIENT DATA AND STATISTICAL
TARGET STRUCTURE ESTIMATION

B. Borden, R. J. Dinger, and G. Hewer
Research Department, Physics Division, Code 3814
Naval Weapons Center, China Lake, CA 93555

Asymptotic inverse scattering has long been able to reconstruct the uniform convex surfaces from which a sufficiently large amount of scattering data have been collected. However, realistic targets are not usually uniform, not strictly convex, and rarely can the scattering data be obtained from all aspects. Under these restrictions, geometrical optics methods are unable to separate the effects of varying target reflectivity coefficients from local curvature effects, and deterministic surface recoverability is not usually possible. By using a small amount of relative phase information instead of pure amplitude data, these considerations can be modified.

Phase gradient data have long been used in target tracking systems. The statistics of the error vector in these tracking situations are well understood; under very general assumptions about the statistical properties of a very complex target, it can be shown that the error depends on gross target structure parameters and not on local reflectivity. By using this fact coupled with maximum likelihood estimation techiques, a statistical structure estimation scheme has been devised that

1) Ignores the complications created by local morphology,
2) Requires only high frequency data collected over a very narrow set of aspects,
3) Allows for gross structure parameter estimation.

With some _a priori_ information added, it is believed that these kinds of properties may make for a general target classification technique.

We review the statistics of the scattering process, discuss the estimation technique, and show how it can be applied to scattering data.

ON THE TOLERANCE OF MICROWAVE IMAGES TO DISTORTION IN THE RADIATION FIELD

Bernard D. Steinberg
Valley Forge Research Center
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Microwave images are highly tolerant to certain types of

1. Distortions in the radiation field,
2. Errors in measurement of the radiation field,
3. Circuit and system errors in the Butler matrix or digital beamformer.

The phenomenon is demonstrated with microwave images of outdoor scenes at distances of 50 m to 10 km. The resolution in these images is very fine, typically 1-3 m both in range and cross range. Images are compared for various amounts of amplitude and phase distortion of the measurements of the radiation field, as well as errors in the image-forming process.

A theory is presented to account for the observations.

The research was supported by the Army Research Office and the Office of Naval Research.

PASSIVE, AIRBORNE, SYNTHETIC HOLOGRAPHIC IMAGING OF TERRESTRIAL FEATURES WITH RADIO WAVES

G. Tricoles
6144 Lourdes Terrace, San Diego, CA 92120
and
R. A. Hayward
6730 Amberly Str., San Diego, CA 92120

In attempting to locate and display surface traces of geological faults we utilized holograms that were formed by an airborne receiver of radio waves broadcast by commercial stations.

The wave propagation mechanism is apparently a vertically polarized ground wave which is scattered by structures on the Earth's surface. The receiving antenna received both horizontally and vertically polarized waves.

One dimensional, line holograms were formed by recording received real-valued intensity during aircraft motion. The holograms are interference patterns, apparently resulting from interference of the scattered and illuminating waves.

Images were computed from a hologram by first multiplying the measured data by a quadratic lens function and then Fourier transforming the product. Actually, pairs of images were formed, one on each side of the line hologram. To resolve the ambiguity, images from distinct holograms were multiplied. Resolution was improved by multiplying images from up to four holograms.

Although image quality was well below that from microwave synthetic aperture radars, the images produced by the new technique display the locations of a surface trace of a fault. In addition ponds, buildings and other terrain features were displayed.

SUPERRESOLUTION IN THE NEAR FIELD

Chaolun Jin and B.D. Steinberg
Valley Forge Research Center
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

In recent years, nonlinear spectral analysis has become a subject of growing interest in the field of phased array signal processing. The major reason for the interest is the potential for superresolution beyond conventional methods, such as the Black-Tukey method of estimation of spectra. Two popular methods of nonlinear spectral estimation which have demonstrated a considerable increase in resolution are Maximum Likelihood Estimation by Capon and the Maximum Entropy Method by Burg which has been designated the autoregressive method.

These methods as well as many others suffer from being unable to resolve coherent targets or sources. A recent contribution by Ajay Luthra of the University of Pennsylvania solves this problem. We call it Luthra's method (LM). LM takes a direct approach to the problem of obtaining the weights for the all-pole model from the measured field samples.

The paper discusses tests of LM on near-field microwave image data obtained from the Valley Forge Research Center (VFRC). This method, as well as other superresolution techniques, are normally applicable only to point targets in the far field. Image data obtained from VFRC are generally in the near field. Performing an experimental test of LM on real data requires modifications to LM to make it fit the near-field situation. In this study, both adaptive beamforming, which has been very successful in high microwave imaging with the Valley Forge radiocamera, and Fresnel-term correction are tested and compared.

APPLICATION OF ADAPTIVE BEAMFORMING TO AIRCRAFT IMAGING

S. Hassan Taheri
Valley Forge Research Center
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

ABSTRACT

Imaging of aircraft using sequential target returns as the aircraft moves along a curvilinear path is considered. The equivalence of differential Doppler processing and the equivalent synthetic aperture radar are pointed out, and advantages of the latter technique are discussed.

With reference to actual measured data, adaptive beamforming techniques as used in the Valley Forge Radio Camera systems are shown to yield superior images. In addition, this approach to processing relaxes the stringent requirements on the trajectory estimation and gross Doppler removal procedure that exists in differential Doppler processing.

IMAGING OF OBJECTS BEHIND A RANDOM SCREEN USING PARTIALLY-COHERENT RADIATION

Ronald L. Fante
Avco Systems Textron
Wilmington, MA 01887

In this paper we will consider the imaging of an object located an arbitrary distance behind a random phase screen, for the cases when the object has an arbitrary state of surface roughness and the incident radiation has an arbitrary degree of spatial coherence. Detailed results will be presented for the limits of smooth and diffuse objects illuminated by short-wavelength radiation that is either spatially incoherent or spatially coherent.

DISCRIMINATION OF COMPLEX RADAR TARGETS WITH E-PULSES AND SINGLE-MODE EXTRACTION SIGNALS

K.M. Chen, D.P. Nyquist, E. Rothwell, W.M. Sun, N. Gharsallah
M. Blischke and B. Drachman*
Dept. of Elect. Engr. & Sys. Sci., Dept. of Mathematics*
Michigan State University, East Lansing, Michigan 48824

Complex radar targets can be discriminated by convolving their radar returns with their synthesized, aspect independent, discriminant signals that include Extinction-pulse (E-pulse) and single-mode extraction signals. When the discriminant signals of an expected target are convolved numerically with the radar return of that target, the convolved outputs give zero or single-mode responses in the late-time period. When the discriminant signals of the expected target are convolved with the radar return from a different target, the resulting signals will be significantly different from the expected zero or single-mode responses, thus, the differing target can be discriminated.

The discriminant signals of a target are synthesized on the basis of natural frequencies of the target. Since the natural frequencies of a complex target are very difficult, if not impossible, to be determined theoretically, they are extracted from the pulse response of its scale model measured in the laboratory with the application of some theoretical methods developed by our group. After the natural frequencies of the complex target are determined, the E-pulse and the single-mode extraction signals of the target can be synthesized. These discriminant signals are then used to convolve with the pulse responses of the target measured at various aspect angles. The convolved results have demonstrated the capability of the scheme to discriminate between complex targets at any aspect angle.

For the purpose of demonstration, two complex targets, scale models of McDonnel-Douglas F-18 airplane and Boing 707 airplane which have similar sizes but different geometries, are used.

This research was supported by Naval Air Systems Command under Contract N00019-85-C-0411.

WYNDHAM B

B-20—ARRAYS AND REFLECTORS

Chairman: R.M. Bevensee

THURSDAY-PM

DIVERSITY TECHNIQUES FOR SIDELOBE REDUCTION IN PHASED ARRAY ANTENNAS

H.M.Subbaram and B.D. Steinberg
Valley Forge Research Center
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Transmitter location and frequency diversity will be employed to drastically reduce the side radiation pattern of phased arrays in the following manner. The transmitters, located both inside and outside the receiving array, illuminate the field of view in sequence. Each transmitter also hops over a set of frequencies having a narrow bandwidth. The returns from all the transmissions are then combined coherently to image the field of view. A frequency diversity technique developed previously (B.D.Steinberg and E.H.Attia, IEEE Trans. Ant. and Prop., vol. 31, Nov. 1983) incoherently recombined the radiation field from each transmission to estimate the image. This technique required a large bandwidth in order to effectively suppress the side radiation pattern of the synthesized array.

It will be shown that coherent recombination of the received signals from each transmission (i) changes the receiver location (in wavelength units) each time a different frequency is transmitted, and (ii) adds the transmitter location to the receiver location in the kernel of the Fourier or Fresnel transform that is employed to image the field of view. Therefore, a MKN element array can be synthesized from an N element receiving array by hopping over a set of M different frequencies transmitted sequentially from each of K different locations. Thus, the peak and average sidelobe level of the synthesized array are about 1/MK times smaller than those of the initial thinned aperiodic receiving array. Further, we show that the length of the synthesized array is the sum of the lengths of the transmitting and receiving arrays; therefore the resolving power of the system can also be improved by using transmitter location diversity.

METHOD OF MOMENTS (NEC) MODEL OF A WIDEBAND ARRAY OF PRINTED DIPOLES

P. Elliot
Sperry Corporation
Waltham, Massachusetts 02154

A. Bucceri
Sperry Corporation
Great Neck, New York 10020

The scattering parameters ($S_{1,j}$) of a 5x5 planar array of strip dipoles have been calculated using the Numerical Electromagnetics Code - Method of Moments (NEC-MOM). The results of this model were compared with measurements on a 10x10 array. The close comparison demonstrates the viability of using a wire grid to model strip dipoles, and of using the impedance properties of a small array of wideband radiators to predict the performance of a large array.

Electrically wide, planar dipoles were modeled using a grid of wires with about 20 wire segments per dipole. The width of the strip for each dipole was chosen to be .12 wavelengths at the center of the octave band of interest. The matching feed network and the source or terminating network at the driving point of each dipole was included in the model. The number of dipoles in the array was limited by the computer run time for a large number of wire grid segments.

Close agreement is demonstrated between the measured and calculated results, despite the difference in number of dipoles that comprise the arrays. The $S_{1,j}$ parameters between the center element of the array and other elements were accurately predicted. The sum of these S parameters yielded the active reflection coefficient of the center element, which was compared with the measured results and the grating lobe series calculation for an infinite array.

NEGATIVE INPUT RESISTANCE CALCULATED FOR THE CENTER ELEMENT OF A BROADSIDE ARRAY

P. Elliot, D. Lamensdorf
Sperry Corporation,
1601 Trapelo Road, Waltham, Massachusetts 02154

A negative active input resistance (or an active reflection coefficient greater than one, also known as scan blindness) was found to occur in the broadside direction for the central radiators of a finite, two-dimensional array of dipoles. This effect has previously been described only for phased arrays when scanned off broadside (e.g., R.C. Hansen, "Microwave Scanning Antennas" v. II, p. 340). The negative resistance was observed using a computer model for dipole arrays. The Numerical Electromagnetic Code - Method of Moments (NEC-MOM) used to model the arrays has been shown to accurately predict the input parameters and coupling for arrays of dipoles.

The real part of the mutual coupling between dipoles can be negative over a narrow band of frequencies (R.S. Elliott, "Antenna Theory and Design", p. 333). The cumulative effect of this negative mutual coupling by several dipoles surrounding a central one is to create a negative input resistance at that dipole. Power is being coupled into the dipole with the negative input resistance from the other dipoles in the array. The total power radiated by the array is still positive, however.

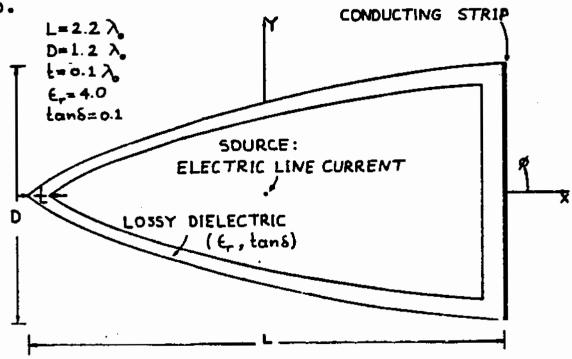
The broadside array configurations which yielded a negative resistance were excited in the "forced" mode described by Hansen (v. II, p. 211). This excitation assumes an ideal voltage source with zero internal impedance driving each element of the array. This situation is approximated when distributed solid state sources with a very low internal impedance are used to excite the array. Several array configurations illustrate the phenomenon and how it can be overcome or avoided.

ANALYSIS OF TWO-DIMENSIONAL LOSSY RADOMES OF ARBITRARY CROSS SECTION WITH OR WITHOUT REFLECTORS

Ercument Arvas
Rochester Institute of Technology
Rochester, NY 14623

Tapan K. Sarkar
Syracuse University
Syracuse, NY 13210

A simple moment solution is given for the problem of the electromagnetic transmission through two dimensional radomes of arbitrary cross section. The radome is composed of one or more layers of lossy dielectric shells of arbitrary cross sections . The reflectors consist of conducting strips next to the outer surface of the radome . The equivalence principle is used to replace the surfaces of the radome and the strips by equivalent electric and magnetic currents. The boundary conditions on the tangential component of the total electric field yields a set of coupled integral equations for the equivalent currents. The integral equations are solved by the method of moments with pulse expansion and point-matching technique. The effects of the surface-wave excitation and the interaction among the various portions of the dielectrics and the reflecting strips are automatically included in this solution. Computed results are the equivalent surface currents, the near field and the far field. The computed results are in very good agreement with whatever published data available. The figure below shows a two dimensional Von Karman shape radome backed by a reflecting strip.



A NUMERICAL TECHNIQUE TO HANDLE REFLECTOR SURFACE TOLERANCE

Y.P. LOH
GENERAL ELECTRIC COMPANY, SPACE DIVISION

The surface tolerance effect of a reflector system has been modelled and represented by two factors: the surface phase factor (SPF), and the surface normal factor (SNF). SPF accounts for the optical path perturbation due to the uncertainty of the reflector surface location. The uncertainty of the direction of the surface normal vector is accounted for by the factor SNF.

The SPF and SNF of a parabolic reflector have been implemented and the gain degradation has been computed versus the surface tolerance. The results showed excellent agreement with the prediction based on Ruze's formula (Jhon Ruze,"Antenna Tolerance Theory- A Review",Proc. IEEE,Vol.5,No.4,April 1966,pp.633-640).

The advantages of the numerical approach to handle reflector surface tolerance effect include,

1. The effects of surface tolerance on cross-polarization may be easily obtained.
2. Reflector shapes other than parabolic, or tolerance other than Gaussian, can be handled with ease.
3. For surface tolerances caused by deterministic function of cyclic nature, such as thermal effect and mechanical vibration, the numerical approach provides a key to the solution of those problems.

The derivations of SPF and SNF for various cases and implementation considerations are described. Also, examples are included to illustrate the utility of this work.

DUAL SHAPED SUBREFLECTORS FOR RECEIVER FEED SYSTEMS

Heinrich Foltz
Electrical Engineering Research Laboratory
The University of Texas at Austin

In high performance reflector antenna feed systems, careful attention must be given to the spillover, illumination, phase, and blocking efficiencies. Efficiency improvement is possible with special multimode feed horns of dielectric feeds, but for broadband applications and at millimeter wavelengths shaped subreflectors in combination with conventional feeds may be preferable.

This paper describes the design and testing of dual shaped subreflectors (DSS) for the Texas 5-m radio telescope. The subreflectors are arranged in a folded Gregorian configuration. They were synthesized using geometric optics. The synthesis procedure is related to that of Galindo and Mittra but has been simplified so that only a single differential equation needs to be solved and exact solutions are guaranteed.

Experimental results shows agreement with the design objectives. These objectives included more uniform aperture illumination, less illumination of the central blocked region and reduced spillover for the DSS as compared to conventional feeds. Presently DSS systems are being designed to improve coupling from quasi-optics receiver front-ends to open-sturcture mixers in sub-millimeter receivers, and to match the front-ends to the primary reflector. These systems should offer higher aperture efficiencies and reduced noise temperatures.

RF-TRANSPARENT STRUCTURES FOR FEED SUPPORT IN SPACECRAFT ANTENNAS

R.D.Graglia, M.Orefice
Dipartimento di Elettronica, Politecnico di Torino
C.Duca degli Abruzzi 24, 10129 Torino, Italy

The increasing number of services to be provided by modern spacecrafts often requires several antennas and an efficient use of the payload platform area. In such cases, the support structures of feeds and/or subreflectors may intercept and distort the RF field radiated by some antenna on the spacecraft. It is therefore important to assess design criteria in order to minimize these effects, and to obtain a maximum transparency of the support structures.

In order to have structures with good weight and mechanical characteristics, the use of advanced composite materials, i.e. fibre reinforced plastics, is almost mandatory, in particular of those with good dielectric properties, as glass fibre or aramid fibre (kevlar).

The center fed reflector is the typical case where the scattering of the feed (or subreflector) supporting structure is very important: support struts have generally metallic characteristics, and their effects are generally studied with various existing methods for the analysis of the blocking of struts and obstacles. Conversely, if the structure is made of penetrable (dielectric) material, its analysis is more complex.

The feed (or subreflector) support may consist of planar or locally planar structures (e.g. a large cone or cylinder surrounding the subreflector, or a pyramidal tower), or of small cylindrical structures (e.g. a tripod, or a truss).

In the planar case, a theoretical approach is relatively easy, by using the transmission line equivalence and computing the reflection and transmission coefficients. Typical structures are sandwich, thin or thick sheet: for each of these types design guidelines will be presented, which allow to design them in order to obtain satisfactory transparency characteristics for a given frequency or incidence angle. Diffraction effects of the edges have then to be taken into account.

Structures made with small cylindrical elements require a complex analysis, except when dealing with circular cross section and neglecting mutual interaction among the various members. A detailed analysis with Moment Method technique for various cross section configurations has been carried out, and also in this case design criteria will be presented.

Measurements have been done in order to verify the theoretical prediction of transmission and reflection performance. Tests have been made both in free space and in waveguide, showing good agreement with computed values.

PHILA. NORTH
B-21—SPECIAL SESSION ON NUMERICAL METHODS
Chairman: C. Butler
THURSDAY-PM

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THE METHOD OF MOMENTS IN ELECTROMAGNETICS

Roger F. Harrington
Department of Electrical Engineering
Syracuse University
Syracuse, NY 13210

The method of moments is a generic name given to projective methods in which a functional equation in an infinite dimensional function space is approximated by a matrix equation in a finite dimensional subspace. Any projective method can be put into the language and notation of the method of moments, hence the concept is very general. Any linear field problem can be formulated either by differential equations (Maxwell's equations plus boundary conditions) or by integral equations (Green's functions plus superposition). Furthermore, neither the differential formulation nor the integral formulation for any particular problem is unique.

Differential formulations plus the method of moments can be used to obtain the finite-difference and the finite-element methods. Such methods are usually characterized by large, sparse matrices. Special solution techniques, such as iterative methods, are often used to handle the large matrices. These methods, and their advantages and disadvantages, will be discussed by other speakers.

Integral formulations plus the method of moments are what most of us think of when discussing the method of moments. One of the simplest electromagnetic applications is to wire antennas and wire scatterers. More difficult applications are to conducting bodies of arbitrary shape, and to dielectric bodies. All of these problems can be discussed in terms of generalized network parameters, a name given to the resultant matrices. Some advantages of the integral formulation over the differential formulation are: (1) The unknown is a one or two-dimensional current instead of a three-dimensional field. (2) The boundary conditions at infinity are incorporated into the solution via the Green's function. (3) The inverse of the moment matrix gives, by a matrix multiplication, the current distribution for any field excitation. A disadvantage of the integral formulation over the differential formulation is that it is more difficult to treat complicated geometries and media inhomogeneities. A disadvantage of the integral formulation over the Geometric Theory of Diffraction is that the wire or body size is limited by the size of the matrix that can be handled. In practice, for wire problems one is usually restricted to arbitrary wires tens of wavelengths long, while for bodies, one is usually restricted to arbitrary surfaces a few square wavelengths in area. These restrictions could be removed by judicious choice of expansion and testing functions, but this is difficult to do. The ultimate limitations to the method are set by the ingenuity of the investigator in formulating the solution, and by the size and speed of the computers available.

AN OVERVIEW OF TIME-DOMAIN INTEGRAL-EQUATION MODELS IN ELECTROMAGNETICS

E. K. Miller
Department of Electrical and Computer Engineering
Nichols Hall, The University of Kansas
Lawrence, KA 66045-2969

Computational electromagnetics embraces a wide variety of formulations and numerical procedures. The basic features which distinguish among the various approaches that might be chosen for linear problems is how the fields are propagated spatially and how they are varied temporally. Spatially, fields can be propagated using Green's functions, modal expansions, rays and the basic Maxwell curl equations. Temporally their time variation may be either harmonic as in the frequency-domain, or impulsive as in the time-domain. Given the number of permutations that can arise from the choices available, it is not surprising that many different approaches have been developed that can provide essentailly equivalent information.

In this paper, we examine the specific approach of using a time-domain integral-equation (TDIE). The basic formulation will be outlined and illustrated by application to a simple problem to illustrate its salient features. Its advantages, limitations, and computational characteristics will be summarized in terms of the problem types to which it is applicable, the kinds of information which it can provide, and compter storage and running time required. Our goal is to characterize models using the TDIE and to put the approach into perspective relative to other tools of compuational electtromagnetics.

THE FINITE-DIFFERENCE TIME-DOMAIN (FD-TD) METHOD FOR ELECTROMAGNETIC SCATTERING AND INTERACTION PROBLEMS

Allen Taflove
EECS Department, Northwestern University
Evanston, IL 60201

Korada Umashankar
EECS Department, University of Illinois at Chicago
Chicago, IL 60680

The finite-difference time-domain (FD-TD) method involves a direct solution of Maxwell's time-dependent curl equations without resorting to formulation of potentials. Simple central-difference approximations for the required space and time derivatives are used to achieve a sampled-data reduction of the continuous electromagnetic field in a volume of space, over a period of time. Space and time discretizations are selected to bound errors involved in the sampling process, and to insure numerical stability of the algorithm. E and H field components are interleaved in space to permit a natural satisfaction of tangential field continuity conditions at media interfaces. The resulting system of equations for the fields is fully explicit, so that there is no need to set up or solve a set of linear equations, and the required computer storage is proportional to the electrical size of the volume modeled.

This paper reviews the formulation of the FD-TD method, and briefly reviews recent applications in modeling radar cross section, coupling through thin slots and to multiconductor cables, and inverse scattering in one and two dimensions. To enhance understanding, the application of FD-TD to a simple two-dimensional forward scattering problem will be covered in more detail.

FD-TD has a number of strong points, including ability to achieve highly detailed models, a dimensionally-low computer resource requirement for such problems, ability to take advantage of modern vectorizing and multiprocessing computer architectures, and ability to interface with other detailed approaches such as the method of moments (MOM). The limitations of FD-TD include the need to re-run a problem when the incident wave angle is changed, and the dispersive effect of the discrete space lattice upon pulse propagation. Both strong points and limitations of FD-TD are discussed.

This paper concludes with a discussion of what types of problems FD-TD is suited for, and why. Factors such as availability of supercomputer time are included in the discussion. Research horizons such as incorporation of conformal curved surfaces, large-scale multiprocessing, and single-point far-field reconstruction of scattering shapes are summarized as time permits.

Finite Element Methods in EM Computations*

K. K. Mei

Department of Electrical Engineering and Computer Sciences
and the Electronics Research Laboratory
University of California, Berkeley, CA 94720

Abstract

Frequency domain electromagnetic computations using finite element methods have been applied in hybrid with integral equations and with harmonic expansion methods, starting in 1972. The harmonic expansion method has since solved scattering by bodies of revolution, two bodies of revolution, and by buried and partly buried bodies of revolution. It is evident that the success of the harmonic expansion method is the consequence of its ability to take advance of axial symmetry. For an arbitrary 3-D problem the expansion method is just as clumsy as other methods, so no progress has been made. Time domain finite element is quite a different story. There is evidence that it can solve 3-D problems with greater ease than other methods. Results will be shown.

*Research sponsored by U.S. Army Research Office Contract DAAG29-84-K-0067 and the Office of Naval Research Contract N00014-84-K-0272.

APPLICATION OF THE GENERALIZED CONJUGATE GRADIENT METHOD FOR THE SOLUTION OF ELECTROMAGNETIC FIELD PROBLEMS

Tapan K. Sarkar
Department of Electrical Engineering
Syracuse University
Syracuse; New York 13244-1240
(315) 423 - 3775

ABSTRACT : For a nonhermitian operator A, the conjugate gradient method solves the normal equations A*AX = A*Y, instead of solving the operator equation AX = Y directly. Here A* denotes the adjoint operator. It is demonstrated that the conjugate gradient method is numerically very stable in the solution of highly illconditioned systems of equations (condition number 10**30) and also for the solution of extremely large systems of equations (16000 unknowns).

Even though in the actual computations A*A is never formed, however the condition number of the original operator equation is squared in the solution of A*AX = A*Y. In this presentation the original conjugate gradient method is reviewed. Also an extension of the original conjugate gradient method is presented which solves AX = Y directly without solving A*AX = A*Y. Hence the new method (henceforth termed as the generalized conjugate gradient method) is roughly three to seven times faster than the original conjugate gradient method desribed in IEEE Trans on Ant. and Propagat. Oct 1985.

Numerical results are presented to illustrate the efficiency of the new method over the conventional conjugate gradient methods. It is also shown how the utilization of the fft can further reduce the computation time. Finally it will be illustrated as how to solve radiation and scattering from straight wire antenna problems in the order of N steps as oppposed to N squared steps taken by conventional matrix methods.

A HYBRID-ITERATIVE METHOD FOR SCATTERING PROBLEMS

Gary A. Thiele, Ph.D.
Graduate Engineering and Research
University of Dayton
Dayton, Ohio 45469

A new technique, named a hybrid-iterative method (HIM), is presented which computes the induced currents on an arbitrary, perfectly conducting scatterer. The technique is an evolution from two previous techniques developed earlier. The first of the previous techniques used the moment method to compute correction currents to an optics-type current. The second of the previous techniques effected a significant improvement by eliminating the use of the moment method to obtain the correction currents, using iteration to obtain them.

The technique described here incorporates the edge diffraction theory and the Fock theory into the ansatz of the iterative scheme. This procedure speeds up the algorithm as well as extending the range of problems that can be solved by the iterative scheme. Furthermore, the technique described in this paper incorporates the correction currents into the optics currents thereby substantially reducing the computation time. For intermediate size and larger bodies, the CPU time is significantly less than that of the moment method. We list the following important points:

i) Incorporating edge diffraction theory and Fock theory eliminates the need for computing higher-order correction currents. That is, speed of convergence is improved. Frequently, zeroth-order optics currents themselves furnish sufficiently accurate solutions. CPU time requirements are, therefore, less demanding.

ii) As the size of the closed body is increased our technique is computationally more efficient than method of moments. As an example, our technique requires only one-third to one-quarter the CPU time required by the MM to compute the currents on a 3.7λ square cylinder. For larger scatterers, the advantage in CPU time is increasingly higher.

iii) Even though the technique has been demonstrated only for 2-D, perfectly-conducting scatterers, it may be extended to more complicated structures like coated scatterers and 3-D bodies.

Results are presented for a variety of curved and edged two-dimensional cylinders.

ON SOME ITERATIVE APPROACHES TO SOLVING A CLASS OF ELECTROMAGNETIC SCATTERING PROBLEMS

R. Mittra and C. H. Chan
Electromagnetic Communication Laboratory
University of Illinois
Urbana, Illinois 61801

The purpose of this paper is to discuss three iterative approaches for solving electromagnetic scattering problems that provide alternatives to the widely-used Conjugate Gradient Method (CGM) of iteration. While the CGM approach has several theoretical and numerical attributes that make it a versatile and valuable tool for many problems of interest, there are situations involving a wide class of electromagnetic problems where it exhibits certain limitations that must be overcome before its application to these problems can be regarded as practical. Specifically, these limitations are: (i) slowness of convergence; (ii) non-convergence due to an ill-conditioned nature of the operator and build-up of round-off error; and, (iii) inability to treat multiple incident fields in a simultaneous and numerically efficient manner.

In this paper we discuss some concepts for enhancing the convergence of the iteration procedure by choosing certain directions for the basis vectors that are different from those prescribed by the conjugate gradient method. We also present some approaches to preconditioning the operator that attempts to modify the eigenvalue spectrum of the operator and, hence, improves its condition number. Finally, we present an iterative technique that employs a set of prechosen basis functions (in contrast to those recursively generated by following the CGM procedure), and is well-suited for solving the multiple r.h.s. problem. Numerical examples illustrating the use of these algorithms are included in the paper.

SALON 3/4
B-22—ELECTROMAGNETIC THEORY III
Chairman: D.L. Sengupta
THURSDAY-PM

STEADY AND SHOCK CURRENTS INDUCED BY ELF-LF ELECTRIC FIELDS IN HUMAN BODIES AND METALLIC OBJECTS

C.J. Lin, Department of Electrical Engineering
University of Detroit, Detroit, Michigan 48221
H.R. Chuang, K.M. Chen, Dept. of Electrical Engr. & Sys. Sci.
Michigan State University, E. Lansing, Michigan 48824

An accurate and efficient numerical method based on surface charge integral equations for quantifying the interaction of ELF-LF electric fields with a realistic model of man has been developed by our group recently. With this method, it is possible to calculate (1) induced surface charge on the body, (2) induced electric fields on the body surface and inside the body, (3) induced current desnity inside the body, and (4) the open-circuit potential and the short-circuit current between the body and ground as functions of the grounding impedances.

This method has been extended to determine the open-circuit potential and the short-circuit current induced in a human body with arbitrary posture and in a metallic object such as a vehicle by the ELF electric field emitted by an extremely high voltage (EHV) power line. When a man and a nearby vehicle are both exposed to the same ELF electric field, a shock current, which is a few orders of magnitude higher than the steady state short-circuit current, may be generated between the man and the vehicle through spark or contact. To analyze this shock current we have developed equivalent circuits for the human body and the vehicle based on their calculated open-circuit potentials and short-circuit currents. The time-dependent behavior of the shock current is then determined from a transient analysis of a system composed of the equivalent circuits.

Other topic considered in this study is the calculation of the induced electric field inside the human body based on an electric field integral equation. This equation is numerically solved with the conjugate-gradient method and the Gauss-Seidel method in a super computer. The numerical results of this method are compared with that generated by the surface charge integral equation method.

THE MONOPOLE ON A FINITE GROUND PLANE

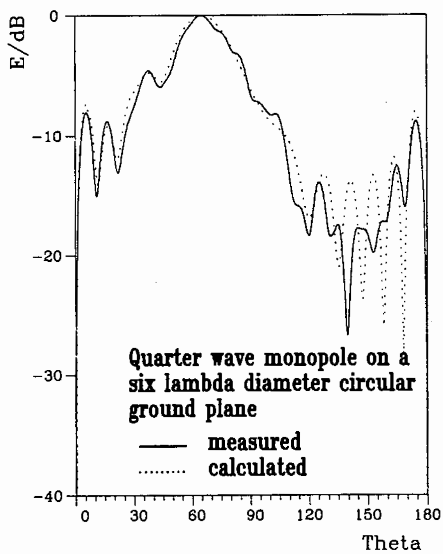
H. Bach and J. Hau Lemanczyk
Electromagnetics Institute, Technical University of Denmark

The fundamental problem of a monopole mounted on a finite ground plane has been a conundrum which has interested researchers since the time of Fresnel. Numerical solutions, primarily GTD, when compared to available measured data has only led to both becoming suspect. The GTD solution for the case of the square ground plane is straight forward enough, however it has been alluded that this is also an acceptable solution for the case of a monopole mounted on a circular ground plane. In an attempt to finally answer these questions about what at first is a simple problem, a project encompassing GTD calculations for monopoles on finite ground planes as well as precise measurements carried out on a highly accurate spherical near field antenna range has been carried out.

The scope of the project was to calculate and measure three sizes of ground planes both square and round measuring six, ten and twenty wavelengths and in each case there was mounted a quarter, half and three quarter wavelength monopole giving a total of eighteen cases to be investigated.

The GTD calculations employed an improved formulation for the direct field from the monopole. In the case of the circular ground plane, the necessary caustic correction is included. Measurements were carried out on the TUD-ESA Spherical Near Field Antenna Test Facility at the Technical University of Denmark. Both a square and circular ground plane were fabricated with their size being varied by appropriate choice of frequency. Monopoles of various lenghts could then be mounted as required.

In the figure can be seen the comparison for one of the in all eighteen cases investigated, between the measured and the GTD calculated results for a quarter wave monopole on a six wavelength circular ground plane. It should be noted that in the theta range between 125 and 165 degrees, the antenna tower and mounting structure significantly disturbs the diffracted field. Outside this region, excellent agreement is observed. The level of the first lobe in both the forward and back directions which displays the expected quality of the focusing effect of the circular plane should approximately be the same due to symmetry and the very small direct radiation in these directions.



MEASUREMENT AND CHARACTERIZATION OF THIN SLOT INTERIOR COUPLING*

A. J. Ludwigsen, H. G. Hudson, R. J. King, K. S. Kunz
Lawrence Livermore National Laboratory
L-156
P.O. Box 808
Livermore, California 94550

Broadband (0.045-18 GHz), wide dynamic range (80-95 dB) measurements were made on a generic interior coupling test object at Lawrence Livermore National Laboratory's EMPEROR EM test facility using an HP8510A network analyzer. The coupling was through an aperture to an interior wire in a cavity. The current at the base of the wire was measured. For this coupling geometry the current response was attenuated below the aperture cutoff frequency, where a wavelength equals the aperture circumference, and, after peaking above the aperture cutoff, rolls off at higher frequency. The region below aperture cutoff offers a nominal 60 dB of attenuation for the apertures employed. Virtually no attenuation in the wire response occurred above cutoff.

We modified the aperture to see if more shielding could be obtained, both below and above cutoff. The aperture was partially blocked with a thin plate to form an annular thin slot. Little change in the response was noted until the slot height and depth were approximately equal and then only a modest amount of additional shielding was seen. The thin plate was farther enlarged so as to overlap the aperture. Shielding was now significantly enhanced (~20 dB) at frequencies below the original aperture cutoff frequency and for frequencies as much as three times higher than cutoff. Above that the reduction was more modest. The test geometry was then modified again to provide an interior offset wall so that the test object appeared to have a very thick hull. The test object in this configuration was positioned to form a continuous deep annular slot of shallow height at its base. Depth to height ratios were varied from 8:1 to 200:1. Somewhat surprisingly there was little additional attenuation provided by the deep slot compared to when the original thin hull was used except for the very high ratios and at very low frequencies where 20 dB attenuation was observed.

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* 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.

AN OFFSET GRID SYSTEM FOR SAMPLING ACCURACY IMPROVEMENT

Y.P. LOH
GENERAL ELECTRIC COMPANY, SPACE DIVISION

The current induced on a reflector is often sampled with a polar coordinate system, where the sampling points are taken as the intesections of a set of concentric circles and a set of radial lines uniformly placed around the circles. The resolution is highest at the center of the grid. The density of the grid points decreases radially outward at a rate of two times the radial distance. If the peak current occurs at or near the grid center, this type of polar grid system is capable of providing satisfactory results. If the peak current location is significantly different from the grid center, then the sampling resolution may be inadequate and significant error may result. This situation is often encountered in reflector system design for beam scan applications.

A simple offset grid system is described in this work to enable the grid center be placed at the peak current location. If a point is picked from a region enclosed by a simply connected curve as the origin, the curve, in polar coordinates (r,θ), may be expressed as $r=f(\theta)$. If a line is drawn from the origin to a point on the curve, the locus of the mid-point of the line segment has an expression : $r=f(\theta)/2$. If the line segment is divided into k divisions, then the locus of the i(th) point on the line is expressed as $r=f(\theta)*(i/k)$, where i=1,,,k. It is obvious that the loci of the k points have exactly the same shape and orientation, regardless of the shape of the simply connected region.

The implementation of the offset grid system has also been described. The conversion from a conventional polar grid system to an offset grid system requires minimal efforts. Though the offset grid is developed primarily for reflector cuurent sampling, one may find its application for other types of problems where a continuous variable is to be represented by discrete numeical values. Examples are included.

AN APPROXIMATE METHOD FOR INCORPORATING THE WALL THICKNESS INTO APERTURE CALCULATIONS

George A. Seely
Electromagnetic Applications Division
Sandia National Laboratories
Albuquerque, New Mexico 87185

A brief review of a method for incorporating the wall thickness into aperture calculations is given. This approximate scheme gives reliable results for $\lambda \gtrsim 6T$, where T is the wall thickness. The effects of conductive wall losses and dielectric materials in the aperture on the resonance characteristics are considered. Numerical results are presented for a few cases of interest.

GENERAL NUMERICAL PROCEDURE FOR CONCEPTION OF METALLIC AND DIELECTRIC LARGE BANDWIDTH HORNS

C. BROCHARD, J.M. MARTINAUD, J. TOURNEUR
THOMSON-CSF, Division Equipements Avioniques
92242 MALAKOFF-CEDEX, FRANCE

The mixed finite-element method has already been used to compute the solution of the electric field integral equation (EFIE) involving arbitrarily shaped surfaces (A. BENDALI *et al.*, El. Letters, vol 18, 641-642, 1982) where the reaction concept is applied to obtain a variational formulation of the EFIE containing the unknown electric equivalent currents and charges on the surface boundary.

The discretisation is based on the study of a family of mixed finite-elements introduced by P.A. RAVIART and J.M. THOMAS (Lect. Notes in Math., vol 606, 292-315) working on polynomial spaces which enable the elaboration of higher order approximations. The lowest order approximation leads to a set of basis functions proposed by RAO *et al.* (IEEE Trans., AP 30, 409-418, 1982) in an other approach.

Using the principles of the formulation, it is possible to take into account various homogeneous media and hence to modelise dielectric bodies such as lenses inside or outside the horn. The method has been developped in an industrial context to calculate radiation patterns of electromagnetic horns. For example, with four very closely spaced ridges situated in the throat of the horn operating at 5 GHz, a computational time of 9 mins is needed on a DEC VAX 8600.

In order to reduce the number of unknows, higher order formulations are being studied like $P_1 x P_1$ or D_2 triangular or rectangular finite-elements. These enhancements can simulate the radiation at a higher frequency without having to recreate the mesh of the model.

Comparisons between calculated radiation patterns and results of measurements always show a high degree of correlation which can be seen in the conference.

Convergence of Numerical Techniques for Electromagnetic Scattering

J. S. Yu, Sandia National Laboratories/Albuquerque
J. W. Williams, Booz, Allen & Hamilton Inc./Albuquerque

Method-of-Moment techniques are often employed to evaluate electromagnetic (EM) scattering from a body of revolution (BOR) that may be lossy and inhomogeneous. Convergence to a unique and correct solution for the EM scattering problem is the main concern of this paper. For a conducting scatterer BOR internal resonance problems are avoided by using a weighted combination of the continuity conditions on boundary surfaces. Discrete current densities on the boundary surfaces were found to be reasonably represented when ten (10) or more patches per wavelength along the BOR-generating curves were used. On each of the patches, there are N coefficients solved for the circumferential modes. These coefficients converge consistently when N exceeds the maximum value of the $k\rho$, where ρ denotes the radial dimension of the scatterer. Details of the EM model become increasingly important as the electrical size and complexity of the scatterer increase. Depending on the smoothness (or lack of it) and total length of the generating curve, there are occasions when more patches per wavelength are needed for satisfactory results. Examples using spheres, disks, cylinders, cones and loops were evaluated for generating curves up to dimensions of 40 wavelengths. Comparisons with exact solutions and measurements are used to validate numerical results. These examples provide practical guidance in modeling techniques for readers who are interested in the application of similar algorithms. They also provide some normalized scattering cross sections for targets that are not readily obtained by other techniques.

CLUSTERING, SURFACE PERTURBATION AND MATERIAL EFFECTS ON ABSORPTION AND SCATTERING BY RAYLEIGH PARTICLES

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

For small particles shape-dependent internal resonances of the induced coupled electromagnetic-vibrational excitations lead to enhancements of the absorption and scattering cross sections σ_A and σ_S at certain critical frequencies, f_c. The f_c lie within the absorption bands of the bulk material of which the particles are composed and correspond to negative values of the real part ε' of the dielectric constant. The strength of $\sigma_A(f_c)$ and $\sigma_S(f_c)$ depends on the amount of internal damping and so increases with $\varepsilon''(f_c)$.

We have tracked (computationally) the variation of the ε_c values corresponding to the major resonances for a number of particle configurations of closely spaced or agglomerated particles as the geometry is changed. Very rapid changes in the ε_c values for some of the resonances occur as the particles become very close or have just merged. We have also tracked similar effects for surface grooves and bosses on individual particles.

The tracking was done assuming the particles were composed of an unphysical low loss material in which ε'' was assumed frequency independent. In this way resonances were only lightly damped and so showed up clearly while, at the same time, particle shape and spacing effects were separated from the effects of the ε'' vs f variation in real materials. For each material, within an absorption band, $\varepsilon''(f)$ varies rapidly and has a local maximum. Therefore plots for real materials of σ_A vs f can be considerably modified from those for the unphysical constant ε'' case. One expects that fine structure will be blurred and possibly that major peaks will be damped out in which case there would be little left of the resonance structure. By computing σ_A vs f in absorption bands for a representative metal (Cu) and representative dielectric (SiC) using published $\varepsilon''(f)$ data we find that not all of the important peaks are heavily damped.

THE ERROR ESTIMATE OF EBCM

Guo Yingjie Mao Yukuan
(Northwest Telecommunication
Engineering Institute, China)

In this paper a formular used to estimate the relative error originated in the extended boundary condition method(EBCM) is presented.

Assume that the scatterer is perfectly conducting. By making use of the inner boundary condition we get a Fredholm integral equation of the first kind

$$Kx=y \qquad (x\in X, y\in Y) \qquad (1)$$

where x represents the surface current, y represents the incident field and K is a non-singular integral operator. Through some mathematical operation eq.(1) can be transformed into the following system of n linear algebraic equations

$$Az=b \qquad (2)$$

The approximate solution of eq.(1) can be obtained from z and the relative error is given by

$$\text{Delta}=\mathcal{E}(1+\|TA^{-1}FPK\|)+\|TA^{-1}F\|\mathcal{E}_1(1+\mathcal{E}) \qquad (3)$$

SALON 5/6
B-23—TRANSIENTS

Chairman: R.J. Porgorzelski
THURSDAY-PM

PROPAGATING PULSED BEAM SOLUTIONS BY COMPLEX SOURCE PARAMETER SUBSTITUTION

E. Heyman and Ben-Zion Steinberg
Department of Electrical Engineering
Tel Aviv University
Tel Aviv 69978, Israel

and

L.B. Felsen
Department of Electrical Engineering/Computer Science
Weber Research Institute
Polytechnic Institute of New York
Farmingdale, New York 11735

The complex source point method is extended to the time domain by considering the field due to an impulsive source point with complex space coordinates and a complex initiation time. The resulting solution, which is a particular analytic continuation of the free space time-dependent Green's function, describes a propagating pulsed beam that has a moving peak along the beam axis. Near the pulse maximum in the paraxial region, this new field type is the Fourier transform into the time domain of the time-harmonic paraxial Gaussian beam field but the solution also accommodates, in closed form, observation points far from the beam axis and observation times long before and after the peak has passed. By corresponding analytic continuation of available space-time Green's functions for various propagation and diffraction environments, one may generate directly the response due to the pulsed beam incident on the environment.

TREATMENT OF TWO-DIMENSIONAL SLOTS IN THICK CONDUCTING SCREENS USING SUB-CELL FD-TD MODELS

Allen Taflove and Fady Harfoush
EECS Department, Northwestern University
Evanston, IL 60201

Korada Umashankar and Benjamin Beker
EECS Department, University of Illinois at Chicago
Chicago, IL 60680

Kane Yee
Lawrence Livermore National Laboratory
Livermore, CA 94550

This paper reports simple, stable, highly accurate models of electromagnetic fields penetrating through narrow slots in thick conducting screens. The general modeling approach is the finite-difference time-domain (FD-TD) method, which has been used previously to provide accurate models of large-aperture coupling into metal cavities. In this paper, the previous work is extended to deal with two-dimensional TE and TM cases where the slot gap is possibly much smaller than one unit cell of the FD-TD space lattice. Key physics that must be modeled properly includes, for the TE case, enhancement of the transverse electric field in the slot gap; for the TM case, exponential field decay due to below cutoff waveguide effects; and for both TE and TM cases, proper field penetration to the shadow side of the slot.

The narrow-slot FD-TD models incorporate field integration contours properly located within or near the slot. The contours permit implementation of the integral form of Maxwell's equations (Faraday's Law for the TE case, Ampere's Law for the TM case) to develop alternative finite-difference expressions at the slot which account for the precise slot geometry and gap. In this manner, even slots of complex cross-section shape within thick screens can be modeled. The aim is to provide a straightforward treatment of coupling through apertures formed by lapped metal surfaces, screw joints, and similar practical joints between conducting surfaces.

Detailed results are shown for the magnitude and phase of E and H fields within, and penetrating behind, canonical two-dimensional slots in thick conducting screens. Results are derived using the new FD-TD narrow-slot models and highly-detailed method-of-moments (MOM) models. Excellent agreement is shown between FD-TD narrow-slot models employing a coarse space grid (0.1 wavelength) and MOM models employing a very fine sampling resolution (less than 0.01 wavelength).

Transient Electromagnetic Scattering and Complex Resonances of a Circular Strip

Jeffery T. Williams
Donald G. Dudley

Electromagnetics Laboratory
Department of Electrical and Computer Engineering
University of Arizona
Tucson, AZ 85721, USA

We present the transient electromagnetic scattering from a thin circular strip mounted on a perfectly conducting sheet. Our source is an electric dipole located along the axis of the strip. The intent of this study is to develop a canonical scattering structure for use in emerging studies in parametric inversion. By applying system identification techniques to the simulated scattered field data, the complex resonances of the scattering object can be obtained. These resonances can, under certain conditions, be related to the geometry and material composition of the scatterer.

The complex resonances of the circular strip can be related to the poles of the scattered field by using a pole series expansion (singularity expansion method). We find these poles by solving the homogeneous integral equation of the induced surface currents on the strip. In addition, the complex resonances can also be related to the high frequency diffracted ray fields of the scatterer. We determine these resonances from a modified GTD solution for the scattered field of the circular strip. This GTD solution includes higher order *slope diffraction*, thus giving a more complete description of the complex resonances of the strip. A comparison of the resonances obtained by both of these techniques is made.

TRANSIENT RADIATION FROM A SPHERICAL ANTENNA- A HYBRID APPROACH

Joseph D. Kotulski
Electromagnetic Applications Division
Sandia National Laboratories
Albuquerque,NM 87185

The transient response of any object can be computed using a variety of methods in different time regimes.The early time region is normally approached by ray methods while the late time region is considered in the context of the modes of the structure. Recent developments in combining these two techniques take advantage of the rapid convergence properties in their respective regimes to synthesize the overall transient response. This hybrid technique is applied to the radiation of a spherical antenna which is excited by a ϕ-independent,δ-gap voltage. The modal solution is separated (in the frequency domain) to give the ray-mode solution. The time response is obtained by taking the inverse Fourier transform of the hybrid ray-mode solution. This is compared to a FFT-generated solution of the original modal sum. The position of the observation point with respect to the excitation is varied and the use of this technique to antennas of different shapes is discussed.

TREATMENT OF WIRES AND MULTICONDUCTOR BUNDLES USING A HYBRID FD-TD / MOM APPROACH

Korada Umashankar and Benjamin Beker
EECS Department, University of Illinois at Chicago
Chicago, IL 60680

Allen Taflove
EECS Department, Northwestern University
Evanston, IL 60201

Kane Yee
Lawrence Livermore National Laboratory
Livermore, CA 94550

The finite-difference time-domain (FD-TD) approach efficiently models complex electromagnetic interactions involving arbitrary-shaped loaded cavities. Either time-harmonic or transient excitation can be modeled for calculating penetrating and scattered fields. If wires or multiconductor bundles are present, it is necessary to use a self-consistent model which properly connects the physics of the wire or bundle with the physics of the enclosing cavity. Complications are introduced because the wire or bundle cross section can either be smaller than one space space cell or overlap several cells, possibly having an asymetrical location with respect to a cell (or cells).

This paper reports the development of a hybrid FD-TD / MOM method based upon electromagnetic equivalences. First, it is shown that a wire bundle of electrically-small diameter can be replaced by a single wire with a properly defined cross section. Next, it is shown that the single equivalent wire can be accurately modeled using FD-TD, even if the wire diameter is much less than one space cell, by building-in the 1/r singularities of the local scattered looping magnetic field and radial electric field for appropriate FD-TD field components near the equivalent wire. Next, once the equivalent wire is modeled using FD-TD within the complex cavity of interest, the total tangential E and H fields on a virtual surface closely surrounding the equivalent wire are computed, and corresponding equivalent magnetic and electric currents on the virtual surface are compiled. Last, these equivalent currents are used as excitation for calculating induced currents on individual wires of the bundle. This computation is made off-line of the FD-TD program, using an auxiliary multiconductor analysis program or the regular integral equation method (MOM), depending upon the mutual coupling of the wires within the bundle. Arbitrary wire loads, interconnections, and branchings can be modeled in this manner.

Excellent validation results for induced currents on multiconductor bundles are reported here for time-harmonic excitation. Cases considered here include bundles comprised of unequal-length wires (some of resonant length) in free-space and cavity environments.

THE TREATMENT OF EDGE SINGULARITIES IN THE FINITE ELEMENT SOLUTION OF MAXWELL'S EQUATIONS IN THE TIME DOMAIN

Scott L. Ray

Lawrence Livermore National Laboratory
P.O. Box 5504, L–156, Livermore, CA 94550

The finite element method is a powerful technique for solving time domain electromagnetics problems. The technique provides accurate results and is applicable to a wide range of complicated geometries. Unlike finite difference techniques, where boundaries and internal structures must be described by "staircase" approximations, finite elements are able to conform to the actual geometry at the expense of increased computer time.

A number of general purpose electromagnetic codes utilizing the finite element method have been developed at the Lawrence Livermore National Laboratory. The basic approach is to first define a mesh which describes the problem at hand. Subsectional basis functions are then associated with the nodal points on the mesh. Electric and magnetic field components are expanded in terms of these basis functions with unknown, time–varying coefficients. The expansions are substituted into Maxwell's differential equations and a Galerkin procedure is used to reduce the resultant system of equations to a larger system of ordinary differential equations in the time variable. These ODE's are then integrated by any of a number of methods.

For computational reasons, relatively simple basis functions have been used in the past. For instance, bilinear functions are used in the two dimensional codes. If the underlying finite element mesh is not too coarse, these basis functions provide sufficient accuracy for most problems. In problems with sharp metallic edges though, errors are introduced as the bilinear basis functions cannot fully represent the field singularities, no matter how fine the mesh. As we are working with time domain solutions, errors are not limited to the vicinity of the edge. Errors, once introduced, propagate throughout the entire problem space.

These errors can be reduced by introducing separate basis functions for nodes located on edges and corners. We have constructed a set of appropriate basis functions for 2–D problems based on the analytic solution for the metallic wedge. These basis functions contain the essential field singularities at the corners allowing more accurate numerical solutions. In a typical problem, only a few nodes require this special, singular element treatment. Thus, the increase in computer time is small.

In this talk, the technique is illustrated by some 2–D waveguide iris studies. The irises have sharp metallic edges, requiring the use of singular elements. Results are compared to the case where bilinear basis functions are used everywhere.

Thin Seam Coupling: A Comparison of an FDTD Technique with an Eigenfunction Technique

Kenneth R. Demarest
Sasan Bakhtiari
Remote Sensing Laboratory
University of Kansas Center for Research, Inc.
Lawrence, Kansas 66045-2969

The Finite-Difference Time-Domain (FDTD) technique is a popular method of analyzing scatterers of small and moderate size by solving Maxwell's equations directly in the time domain. Using this technique, the scatterer is generally modeled as a collection of rectangular blocks (either perfectly conducting or dielectric), and the average electric and magnetic fields in each cell are calculated in a time marching fashion.

Several techniques have been developed to extend the FDTD approach so that geometries with thin apertures can be modeled. One such approach (K. Demarest, 1985, URSI Symposium, Vancouver, pp. 122) utilizes Babinet's principle to model an aperture in a conducting plane in terms of its dual - a magnetic wire. The use of this technique enables the modeling of apertures much thinner than the spatial grid used in the FDTD solution through the partial decoupling of the internal and external regions across the aperture.

In this paper, we compare results of this FDTD technique with those of a frequency domain, eigenfunction technique. The geometry used for this comparison is a hollow cylinder with a circumferential, 90°, aperture. The mode of excitation is a transient current source at the cylinder endcaps. The eigenfunction technique utilizes a Fourier-Bessel expansion in three regions, and the method of moments to enforce the boundary conditions between these regions. The frequency domain results are then transformed to the time domain.

Internal cavity responses calculated by both of these techniques will be compared as a benchmark test of the accuracy of the thin aperture, FDTD technique.

Transient Scattering by a Radial Line joined to a Coaxial Waveguide

Donald G. Dudley
Electromagnetics Laboratory
Department of Electrical and Computer Engineering
University of Arizona
Tucson, AZ 85721, USA

Zhang Shan-jie
Department of Information Physics
Nanjing University
Nanjing, CHINA

We present the transient scattering caused by a branch radial line introduced into the outer wall of a coaxial waveguide. Our purpose is to obtain synthetic data for future use in parametric inverse experiments. In the parametric inverse problem, we shall use the transient reflected fields to estimate the width and depth of the branch radial line.

In the frequency domain, we formulate an integral equation for the tangential field in the aperture joining the coaxial and radial waveguides. We approximate the integral equation by a matrix (method of moments, MOM). We make appropriate use of asymptotics in the series expansions for the fields in both the coaxial and radial regions. We use two expansions of the fields in the branch line and comment on appropriate values of parameters for the use of each. From the approximate solution obtained in the MOM, we produce the scattered reflected fields in the coax over a broad enough range of frequencies to make possible a numerical inverse transform to the time domain. We do the inverse transform with a combination trapazoidal and Filon method. Finally we give data for the scattered transient fields and comment on its use in parametric inverse experiments.

EMP-INDUCED, TIME-DOMAIN GRAZING CURRENT FOR AN INFINITE WIRE OVER THE GROUND

Kenneth C. Chen
Sandia National Laboratories
Electromagnetic Analysis Division
P.O. Box 5800
Albuquerque, New Mexico 87185

The EMP-induced, time-domain current waveform is obtained for an infinite wire over the ground under grazing incidence. In contrast to the published results, the maximum grazing current is found to be slightly larger when the ground conductivity is higher. The grazing angle for maximum current is also found to be smaller when the ground conductivity is higher. For a typical ground conductivity of 10^{-2} S/m, the maximum current is approximately a factor of five larger than the typical value reported in the literature.

SALON 5/6
E-1—NOISE AND INTERFERENCE MODELING AND SYSTEMS PERFORMANCE ANALYSIS

Chairman: J.M. Morris

MONDAY-AM

A GENERALIZED MODEL FOR NOISY SIGNALS IN LOCALLY OPTIMUM DETECTION*

Iickho Song and Saleem A. Kassam
Department of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104

Detectors which are optimum for signal detection in the local case of weak signals have been of considerable interest, because detection of weak signals is more difficult than detection of signals which are comparable in strength to the noise process. Most of the previous reported studies of locally optimum detection in non-Gaussian noise have dealt only with the case of additive noise.

In this paper we consider more general models of noisy signals, and obtain the structures of locally optimum detectors for several cases of interest. For example one rather general model of the noisy observations $\underline{X}_i$ may be specified as

$$\underline{X}_i = a(\theta)\underline{m}_i + b(\theta)\underline{S}_i + \rho(\theta, \underline{S}_i, \underline{N}_i) + \underline{W}_i, \quad i=1,2,\ldots,n.$$

Here $a(\theta)$ and $b(\theta)$ are functions of the signal strength parameter θ, the $\underline{m}_i$ are a deterministic (mean) signal sequence, the $\underline{S}_i$ form a zero-mean random-signal sequence, $\underline{W}_i$ is independent zero-mean additive noise, and the term $\rho(\theta, \underline{S}_i, \underline{N}_i)$ allows the modeling of multiplicative or signal-dependent noise, with $\underline{N}_i$ a noise term generally correlated with $\underline{W}_i$. The above formulation models the general case of vector signals, using which the treatment of array data or narrowband signals in addition to univariate observations is possible. One special case is obtained by taking $\rho(\theta, \underline{S}_i, \underline{N}_i)$ to be (in the univariate case) $c(\theta)S_iN_i$, which models multiplicative noise. Another possibility is to make $\rho(\theta, \underline{S}_i, \underline{N}_i) = c(\theta)N_i$, to model signal-dependent noise.

For several such specific cases of the generalized model, explicit forms of the test statistics of locally optimum detectors will be given, under the assumption that the joint probability density functions of the noise and the signal are known.

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THE EFFECT OF EMISSION NOISE FROM THE ATMOSPHERE ON THE PERFORMANCE OF EARTH/SPACE LINKS AT Ka AND X BAND

Ernest K. Smith
Caltech Jet Propulsion Laboratory
Pasadena, CA 91109

Earth/space telecommunication systems typically employ minimum-noise front ends in their Earth terminal receivers. A consequence is that the increase in noise emission, during a modest increase atmospheric attenuation, will dominate the decrease in the signal-to-noise ratio as compared to the effect of the signal attenuation. Thus with a system temperature of 15 K, a signal attenuation of 0.1 dB will raise the system temperature to 21 K for a 1.5 dB increase in noise, or a resultant S/N decrease of 1.6 dB; of which 94 % is due to increase in the noise. On the other hand if the atmospheric attenuation were 20 dB, the noise level would increase to about 280 K, or about 13 dB; yielding a 33 dB decrease in S/N, of which only 39 % is attributable to the increase in the noise component. Thus the relative importance of noise is a function of the magnitude of the atmospheric attenuation and of the system noise temperature in the absence of this attenuation. The magnitude of the attenuation selected will, in turn, depend on the choice of the percent of time that a desired service is to be available, the location, the operating frequency and time of year.

At 32 GHz, a choice of 90 % service means that the limiting factor will be cloud attenuation. If 99 % of the time (or higher) is chosen, then the limiting factor will be rain. Comparisons of X and Ka band transmission through the atmosphere at these two levels are given.

A conclusion is that cloud attenuation will become increasingly important, as usage of higher frequencies increases, as the cost of LNAs goes down, and as new services such as mobile satellite and direct broadcasting, with their lower reliability requirements become more popular. At the present time there is no statistical model for cloud attenuation.

SECOND ORDER NON-GAUSSIAN NOISE PROCESSES, WITH APPLICATIONS TO ZERO-MEMORY NONLINEAR DEVICES*

David Middleton
127 East 91 Street
New York, N.Y.

The canonical first-order Class A and B models of general nongaussian noise developed by the author since 1974 (D. Middleton, IEEE Trans. Electromag. Compat., EMC-25, 76-106, 1983 and refs. there--in) are extended to second-order distributions. These new results explicitly contain all associated second-order correlations, as well as those of a general additive gaussian component. The first-order formulations are extended to include not only both broad- and narrow--band noise processes, but non-gaussian space-time fields themselves, which are sampled by general arrays and aper tures.

With these specific second-order nongaussian pdf's it is now possible to generalize the "classical" second-order theory of output signal-to-noise ratios, spectra, and covariance functions following zero-memory nonlinear (ZMNL) devices (D. Middleton, Introduction to Statistical Communication Theory, McGraw-Hill, New York, 1960), to in--clude explicitly the many important applications where the inter--ference(which may or may not accompany a desired signal) is highly nongaussian.

Because of the statistical-physical construction of these analytic, or "parametric" nongaussian noise field and process models, the rôles of the physical processes involved may be directly noted in the output results. The general results obtained here are illustrated by a number of examples: nongaussian noise through various nonlinear devices, angle modulation by canonical nongaussian noise (Class A cases), and the output covariances and spectra of full-wave square-law detectors, among others.

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THE CENTROID OF HF INTERFERENCE AND ITS APPLICATION IN SHORT WAVE COMMUNICATION

Zhou Guonai, Yang Shitai
China Research Institute of Radio Wave Propagation

ABSTRACT

The level of HF interference can be considered as the total effect caused by signals from a lot of interference sources in various directions. The levels of HF interferences at various frequencies are different from each other. In order to characterize feature of the interference, we consider the HF band as a whole and define a new parameter Interference Centroid Frequency (ICF).

$$ICF = [\sum_{i=1}^{n} Fi*D(Fi)]/[\sum_{i=1}^{n} D(Fi)] \qquad (1)$$

Where Fi is the i-th frequency, D(Fi) is interference signal power at Fi, and ICF is the first order moment of D(Fi).

The HF interference have been measured by an interference spectrum monitor. from Oct.11 to Oct.28,1984 in Xi An (E 108°54', N 34°18').

By the experiment we have following conclusions:

1. The distribution of ICF at the same time every day is normal .

2. There is high correlation between ICF and foF2.

Based on the main characteristics of ICF, we can use it to estimate the basic maximum usable frequency (MUF_B) on a HF communication link and get real-time optimal communication frequency on the HF link.

The method mentioned above for the real-time selecting HF frequency has three advantages:

Real-time, lower cost and no interference to other usere.

The Performance of a Planar Array With Ideal Nonlinear Elements

Roger F. Dwyer

Naval Underwater Systems Center
New London Laboratory
New London, Connecticut 06320

There is considerable interest in predicting the performance of a planar array with nonlinear elements. For example, a planar array configuration is used in radar and communication systems. However, the interest is based on results formulated from the likelihood ratio. Although, under somewhat restrictive assumptions. Nevertheless, the likelihood ratio suggests performance improvements in certain environmental noise situations supported by experimental measurements.

The objective of the paper is to remove some of the assumptions needed under the likelihood ratio approach. However, the generality of the likelihood ratio is sacrificed in order to obtain specific performance predictions for a planar array of nonlinear elements. The information needed for the performance evaluation is based on the crosscorrelation estimate. In this regard the array configuration, receiver structure, and nonlinear elements are defined. With this information and the crosscorrelation estimate performance predictions are obtained for signals propagating in Gaussian and recurring impulsive noise environments. The performance predictions include the case when impulsive noise is propagating from the same direction as the signal. The results show that temporal and spatial filtering alone are not effective against impulsive noise. Whereas, the nonlinear elements are. Therefore, the total configuration with nonlinear elements generalizes array processing to include impulsive noise environments.

There are M sensors in each horizontal row and N sensors in each vertical column. Further processing utilizes a receiver which converts the data at the output of each nonlinear element into frequency components using a discrete-Fourier transform. The frequency components are then weighted and summed over all spatial sensors. The weights are chosen by maximizing a defined performance measure. However, this optimization procedure does not take into account the debilitating effects of impulsive noise. In order to treat theoretically the inclusion of a nonlinear element, to combate impulsive noise, the concept of an ideal nonlinear element is introduced. The ideal nonlinear element is introduced in the time-domain to facilitate deriving the theoretical performance of the resultant receiver in the frequency-domain. Therefore, the advantage of introducing an ideal nonlinear element is that this concept allows a theoretical performance prediction to be derived.

INVERTED GRAM-SCHMIDT PROCESSING FOR INTERFERENCE CANCELLATION

Kenneth Abend

INTERSPEC, Inc. and University of Pennsylvania
Conshohocken, PA, Philadelphia, PA

The Gram-Schmidt Orthogonalization (GSO) procedure is an efficient method for producing the conventional weight vector

$$\underline{W} = \underline{R}^{-1}\ \underline{S}$$

for suppressing directional interference in an array of sensors. The inverted GSO procedure interchanges the roles of time samples and elements on the array to efficiently produce a weight vector which is the projection of the steering vector onto a linear subspace orthogonal to that spanned by the interference. Here, interference cancellation is achieved by approximating a "MUSIC" type orthogonal decomposition without the necessity for solving N eigenvalues and eigenvectors. By viewing the Hung-Turner-Kullstam algorithm as an inverted GSO procedure, new insights are achieved. Processing can be performed in place (at the element level) with only broadcast data required at the elements and only sums required at a central node. The number of computations at each element is small (though many elements must be used as auxiliaries) and only the number of time samples processed need depend on the number of interfering sources present. This number need not be known ahead of time because the algorithm lets you know when it is finished.

In the conventional application of GSO, the Nth port is the main beam port and the remaining N-1 ports may be auxiliary elements or auxiliary beams. With the desired signal absent, the part of the received signal in the second port that is correlated with the signal in the first port is substracted from the second port so that ports one and two become uncorrelated. This procedure is continued from port to port until the main beam port produces a signal that is uncorrelated with all the other ports. Since directional interference is correlated from port to port, this nulls the interference. The equivalent of the inversion of an NxN matrix is achieved through the more accurate procedure of $\underline{L}\ \underline{D}\ \underline{U}$ decomposition. Both the conventional and a simplified $\overline{GSO}$ algorithm will be discussed. The simplification is usefull when the adapted weights can be applied for signal detection after adaptation.

This GSO procedure requires a number of auxiliary ports determined by the number of interfering sources. By making the signal vectors orthogonal from time sample to time sample, instead of making the signals uncorrelated from port to port, the inverted GSO is adaptive to the number of interference sources.

DETECTION OF A FLUCTUATING TARGET IN BOTH NOISE AND CLUTTER

Jung G. Shin and M. Farhoomand
Department of Electrical Engineering
Stevens Institute of Technology
Castle-Point-Station
Hoboken, NJ 07030

The problem of detecting a fluctuating target in the presence of both clutter and noise is examined. The log-normal clutter which is the case of typical sea clutters and Rayleigh distributed noise are considered.

For both Swerling case 1 and Swerling case 2 targets which are either Rayleigh or log-normal distributed, a class of sub-optimum detectors are suggested. For each of the detectors, false alarm probabilities are evaluated, and the sensitivity of detection probabilities on target-to-noise and noise-to-clutter power ratios are discussed.

Performance comparison is made with other existing detectors through numerical results.

ROBUST SUBOPTIMAL DETECTION

Kenneth S. Vastola and Mete Kabatepe
Department of ECSE
Rensselaer Polytechnic Institute
Troy, New York 12180-3590

Typically, noise not only has non-Gaussian first order distributions, but also complex interdependencies. Further, it is often nonstationary. Since these factors lead to modeling inaccuracies, signal processing systems which are theoretically optimal may not perform as well in practice and may also be hard to implement.

A minimax theory of robustness has been developed which has lead to useful "most-robust" systems. However, we take the opposite point of view: Given a system (dictated by complex implementation or performance constraints), how robust is that system in arbitrary (non-Gaussian, dependent, nonstationary) noise. A recently developed general theory of qualitative robustness is applied to detection of signals in noise. Numerical results illustrating the practical usefulness of these results are presented. In particular the performance and robustness of several suboptimum detectors in Middleton noise is discussed.

SALON 5/6
F-1—EARTH-SPACE PROPAGATION AND ATMOSPHERIC ATTENUATION
Chairman: H.W. Arnold
TUESDAY-AM

SLANT PATH PROPAGATION THROUGH WINTER EAST COAST CYCLONES

ROBERT E. MARSHALL
DEPARTMENT OF MARINE, EARTH AND ATMOSPHERIC SCIENCES
NORTH CAROLINA STATE UNIVERSITY
RALEIGH, NORTH CAROLINA 27650

Severe weather is often associated with winter East Coast Cyclones. Some of these storms rapidly intensify off the Carolina coast and move northward through the heavily populated northeastern corridor. These storms produce bands of heavy liquid and frozen precipitation. These precipitation bands may cause significant attenuation and depolarization events on satellite links. The size, shape, and motion of convective cells within these precipitation bands will influence the behavior of space diversity systems.

The Genesis of Atlantic Lows Experiment (GALE) to be performed between January 15, 1986 and March 15, 1986 will employ a large network of meteorological RADARS to study the structure of precipitation bands associated with these storms. Data from the non-coherent National Weather Service RADARS at Volens, Virginia, Cape Hatteras, North Carolina, Wilmington, North Carolina, Athens, Georgia, and Tampa, Florida will be digitized in one (1) dBZ increments during GALE. This network will be supplemented by a system of coherent RADARS at Fort Fisher, North Carolina, Ocrocoke, North Carolina, Cape Hatteras, North Carolina, and Wallops Island, Virginia. Disdrometers and rain gauges will measure drop size distributions at Cape Hatteras and Fort Fisher.

This paper will summarize the events associated with the GALE measurements. The current status of RADAR and in situ data set analysis and availability will be reported. A preliminary evaluation of single site and space diversity system performance during winter East Coast Cyclones will be given.

DUSTSTORMS AND MICROWAVE PROPAGATION

Safa Haddad and U.A.Salman
Department of Electrical Engineering,
University of Technology , Baghdad , Iraq.

ABSTRACT- Dust samples, collected from storms at 30,70 and 100m heights, are analysed by Scanning Electron Microscope to find the probability density size-distribution by number and to explore the possibility of finding a correlation between particles shapes and sizes. Effects of duststorms on microwave propagation is also investigated.

Samples were placed in five size groups and measured data are presented in tabular form in detail and probability density size distribution is plotted. Calculated values of the proposed shape correction factor, c_s, are in fair agreement with the existing results at lower heights but deviates slightly as height increases. Further, average values of c_s indicate the possibility of non-spherical particles at higher heights in larger number. The average dimension rates, determined statistically from the five size groups of the three samples, do not exihibit any strong evidence of correlation between particles shapes and sizes.

The introduction of c_s reduces attenuation, and phase shift, of microwaves propagating in non-uniform storms. From the illustrations of differential horizontal and vertical attenuations and phase shifts for four particles sizes and different frequencies at 5% moisture and 100m visibility, it is observed that attenuation and phase shifts of microwaves are more in the horizontal than in the vertical plane. Finally, cross polarizations of the waves are also calculated assuming ellipsoidal particles of storms with varying moisture contents and frequencies and the results are discussed.

FREQUENCY DEPENDENCE OF SLANT-PATH RAIN ATTENUATION: MEASUREMENTS AND ANALYSES WITH DISDROMETER DATA

T. Kozu*, J. Awaka*, H. Fukuchi**, and K. Nakamura**

* Radio Research Laboratory (RRL), Tokyo 184, Japan
** Kashima Space Research Center, RRL, Ibaraki 314, Japan

The slant-path propagation experiments using Japanese geostationary satellites CS and BSE have been performed at the Kashima Space Research Center of RRL (Fukuchi et al., IEEE Trans. AP-31, 4, 603-613, 1983). The elevation angles of the CS and the BSE paths at Kashima are 48° and 37°, respectively. In addition to down-link beacon (CS;19.5GHz, BSE;11.7GHz) attenuations, up-link communication channel (CS;28.9GHz, BSE; 14.4GHz) attenuations were measured for more than ten rainfall events during 3 years from 1979 to 1981. We report the properties of attenuation ratios (AR's) obtained from the up- and down-link attenuation measurements and the analyses using raindrop size distributions (DSD's) measured by a disdrometer.

AR's (dB/dB) varied from event to event ranging from 1.8 to 2.4 for the CS link (28.9/19.5GHz, circular polarization) and from 1.3 to 1.9 for the BSE link (14.4/11.7GHz, vertical polarization). Attenuation dependence of AR was also observed for some events. AR's were statistically determined by comparing the cumulative distributions of attenuations. The determined values, which increase slightly with the increase of attenuation level, are 2.0-2.1 for the CS link and 1.5-1.7 for the BSE link.

For examining the relation between each of the properties of AR mentioned above and DSD, AR's were calculated by using the disdrometer data for rainfall events corresponding to the attenuation measurements. For the BSE link, agreements between measured and DSD-derived AR's are very good, while for the CS link, DSD-derived AR's are somewhat larger than the measured ones except for a few events. One possible reason of the discrepancy in the CS link is the effect of the melting layer attenuation. Because, radar observations along the paths found that, for the CS link, most of the measurements were made for relatively light rain with the melting layer, and that, for the BSE link, most of them were made for heavy convective storm.

Although further examination must be made concerning the discrepancy in the CS link, the good agreements in the BSE link suggest that the DSD's on the ground correlate with those along the slant-path and are useful for predicting the frequency dependence of slant-path attenuation.

A NEW TECHNIQUE TO MEASURE COMPLEXPERMITTIVITY OF DUST/SAND SAMPLES OF STORMS AT 10 GHZ AND THIER PARTICLE SIZE DISTRIBUTION

Abdulla.S.A Res. Space And Astronomy Research Center
Al-Rizzo.H.M Res.Ass Scientific Research Council
Mohammed.A.A Eng.Ass.

ABSTRACT:

Sand and/or dust storms are very frequent in the Arab world including Iraq,due to which performance of the microwave communication systems,particularly the microwave links,are severely affected.This immediatily warrants the investigation of the propagation behaviour of microwave during storms.To this end in view,a new technique has been proposed to measure first the complex permittivities of the dust/sand samples collected from the storms as well as the simulated samples at 10GHZ.The suggested technique is based on the principle analysis given by [constantine ,A.B.,et al,IEEE Tran. Geoscience Elec. 16, 316-323] but with a novel approch.In this method,reflection and transmission losses caused by the samples are measured separately by utilizing a circulator in a balanced bridge configration.The permittivities of the samples are also measured by conventional techniques.The two results are found to have good agreement.

Particle size distributions of the sedimentation technique in order to investigate the dust storm effects on microwave propagation.The work is under further invistigation.

COMPARATIVE STUDY OF CUMULATIVE RAIN RATE DISTRIBUTION APPROXIMATION MODELS

MARLENE S. PONTES
CETUC - Pontifícia Universidade Católica
Rua Marquês de São Vicente 225
22453 - Rio de Janeiro - BRAZIL

Log-normal and gamma approximations are extensively used to model rain rate cumulative probability distributions. Recently an alternative model has been proposed by Moupfouma (Ann. Télécommunic., 37, nº 3-4, 1982, pp. 123-128), based on experimental data obtained in an equatorial region.

A comparative evaluation of these three approximations has been performed both for the climates proposed by the CCIR (Radiometeorological data, Rep. 563-2, Prop. in non-ionized media, vol. V) and for rain rate data obtained over a three year period in a tropical climate (Rio de Janeiro, Brazil). The cumulative distributions were obtained by least-square fitting the logarithims of the probability for the available rain rate figures. This procedure provides a better accuracy for low time percentages, associated to higher rainfall rates, which are the most important for rain attenuation prediction. The results show that the log-normal and the Moupfouma approximations are more effective to represent the rain rate cumulative probability distributions.

RAIN ATTENUATION PREDICTION MODELS COMPARISON FOR TROPICAL CLIMATE DATA

MARLENE S. PONTES
CETUC - Pontifícia Universidade Católica
Rua Marquês de São Vicente 225
22453 - Rio de Janeiro - RJ

A large number of rain attenuation prediction models are found in the literature. However, almost all the rain rate and rain attenuation data used to testify these models were obtained in temperate climates.This paper presents a comparative evaluation of several models to predict attenuation, given the point rain statistics, based on measurements taken place in tropical climates.

The comparison included the models proposed by Lin (BSTJ, 56, 1977, pp. 1581-1604), Crane (IEEE Trans. Comm. 28, nº 9, 1980, pp. 1717-1733), CCIR (Rep. 338, Vol. V), Boithias-Battesti (J. Tiffon, Ann. Téléc., 38, nº 5-6, 1983, pp. 245-261), Misme-Fimbel (Ann. Téléc., 30, 5-6, 1975, pp. 149-158) and Assis-Einloft (Ann.Téléc., 32, nº 11-12, 1977, pp. 478-480). The experimental data have been obtained in five 11 GHz microwave links in different regions of Brazil where continuous measurements of rain attenuation were made during one to five years periods. In two of these regions the rain rate was simultaneously recorded and for the remaining three links the CCIR rain cumulative distributions were used.

The results show that for most of the cases the Misme-Fimbel and the Assis-Einloft methods have a good agreement with experimental data.

RAIN RATE AND RAIN ATTENUATION MEASUREMENTS IN A TROPICAL REGION

CLÁUDIO M. EINLOFT LUIZ A.R. DA SILVA MELLO

CETUC - Pontifícia Universidade Católica
Rua Marquês de São Vicente, 225
22453 - Rio de Janeiro - Brazil

A great amount of data on rain rate and rain attenuation statistics obtained in temperate climates have been published in recent years. However for tropical regions, subject to higher rain rates, only a few results are available. This paper reports five years of simultaneuous measurements of rain rate and rain attenuation on a 8.6 Km, 11 GHz commercial link in the urban area of Rio de Janeiro, Brazil. The work is part of an extenside study that intends to cover the climatic regions of Brazil.

The major results of the investigation are: (1) The rain attenuation probability distribution for the link, obtained from continous chart records during the periods from 15th July 1977 to 15th July 1981 and from 15th July 1982 to 15th July 1983; (2) The point rain rate probability distribution taken near to one end of the link during the same period; (3) The theoretically predicted attenuation distribution obtained using the measured rain rate distribution.

The measured attenuation distributions show figures as high as 20 dB rain attenuation exceeded for 0.01% of the worst year. The rain rates have been obtained with 5 min. integration time and than adjusted to 1 min. integration time using the model of Damosso et al (CSELT Rapport Tecnici, VIII, nº 4, 1981, pp.299-302). The corresponding corrected rain rate distributions are used to predict the rain attenuation distributions. For this calculation the Assis-Einloft method (Ann. Télécommunic., 32, nº 11-12, 1977, pp. 478-480), which is an approximattion of the Misme-Fimbel method (Ann. Télécommunic., 30, nº 5-6, 1975, pp. 149-158), is used. The theoretical results are in satisfactory agreement with the measured data in almost all cases.

ANGLES-OF-ARRIVAL FLUCTUATION AT 20 GHZ ON EARTH-SPACE PATH

H. Fukuchi, T. Okuyama, K. Nakamura and K. Okamoto

Kashima Space Research Center, Radio Research Laboratory,
893-1, Hirai, Kashima-machi, Ibaraki, 314 Japan

Because the angles-of-arrival(AOA) fluctuations along an earth-space path affect the quality of space communications systems using high frequency bands with high directivity antennas, a reliable estimation of the AOA fluctuation is considered to be of importance to design a new space communications systems.

The beacon signals of Japan's geostationary communications satellites, CS and CS-2, have been received by a 13 m parabolic antenna with the elevation angles of about 48° at Kashima Space Research Center, Radio Research Laboratory. These signals are circularly polarized waves at 19.45 GHz. The AOAs of the signals were measured by the following two methods simultaneously. One is an interferometer and the other is a tracking error measurement system which has been used in auto-tracking facilities of the antenna. By comparing the fluctuations of AOA measured by above two methods with each other, it was confirmed that the tracking error signals can be used for AOA measurements with sufficient accuracy by applying proper corrections for the antenna movement.

The AOAs of the beacon signals were continuously measured at the rate of one sample per second and were used to derive the standard deviations of AOA over 3 minute interval. The fluctuation of AOA increased in the daytime and was larger in summer than in winter. The main cause of these general characteristics is the fluctuation of refractive index of the atmosphere along the path. In summer, anomalous fluctuations of AOA with the standard deviation larger than 5 milli-degrees were observed. For example, in August, 1982, the standard deviation of 5.5 milli-degrees and the peak fluctuation of ± 25 milli-degrees from the average direction were observed in the daytime. In some of these large AOA fluctuation events, thick clouds were observed near the propagation path. These anomalous fluctuations of AOA seem to be caused by multi-path propagation effects or diffraction due to thick clouds near or along the path.

It is found that cumulative distributions of AOA standard deviations in both elevation(EL) and traverse(azimuth X COS EL) directions are nearly the same. This suggests that the fluctuation of AOA is isotropic on such a propagation path with a large elevation angle.

SALON 5/6
F-2—THEORY OF SCATTERING AND OF GROUND-WAVE PROPAGATION

Chairman: A. Ishimaru

TUESDAY-PM

TRANSIENT RESPONSE OF DIPOLE ANTENNAS ON TWO-LAYER MEDIA

S. Y. Poh, J. A. Kong and M. J. Tsuk

Department of Electrical Engineering and Computer Science
and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

The study of transient electromagnetic waves of dipole antennas in layered media leads to applications in geophysical probing, subsurface communications, and microelectronic integrated circuits with high-speed switchings. Early- and late-time responses of half-space and two-layer media for a transient pulse have been investigated in the literature. A complete time-domain response can also be obtained with the Cagniard-de Hoop method when the reflection coefficients at the boundaries are independent of frequency, a condition satisfied only for nondispersive media.

In this paper we study the complete time response with the double deformation technique, which involves contour integrations on the complex frequency and wavenumber domains. The relevant pole singularities, branch points and branch cuts will be discussed in detail to facilitate physical interpretations of the results. In particular, we identify the significance of a set of poles contributing to the early response and essential for the preservation of causality. Through such an approach, the wave behavior of modes and rays associated with the various singularities on the complex planes can be analysed. We study both vertical electric and magnetic dipole antennas as well as two-dimensional sources on a two-layer medium, where the medium can be dissipative and dispersive. The difference between the transient responses of the electric and magnetic dipoles as a result of the difference in the singularities associated with the Fresnel reflection coefficients will be examined and illustrated.

SECOND MOMENTS OF WAVES AFTER PROPAGATING THROUGH A DISCRETE RANDOM MEDIUM

Likarn Wang and C.C. Yang
Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802

Abstract

Although the effects on a propagated wave from random scattering in a particle-distributed medium have been widely studied, research works were essentially limited in the computation of the first moment of the propagated or scattered wave. This is attributed to the mathematical complexity of the conventional approach when higher moments are evaluated. Recently, a new method for particle scattering has been proposed by one of the authors. In this new method, a correlation function for such a discrete random medium is derived. Having this correlation function, we can use the theory of continuous scattering to discuss the effects of particle scattering including multiple scattering effect. A mutual coherence function is computed in this paper. In doing so, the correlation between the permittivity fluctuation at one point and the wave field at the other point has to be evaluated first. This correlation can be computed using the Novikov-Furutsu theorem when the permittivity fluctuation possesses a Gaussian distribution; however, this is not true in a discrete random medium. Therefore, a new theorem needs to be established. Methods and results for this correlation and the mutual coherence function are presented.

EFFECTS OF NON-SPHERICAL STATISTICS AND MULTIPLESCATTERING ON EM WAVE PROPAGATION IN DISCRETE RANDOM MEDIA

V. K. Varadan, V. V. Varadan, Y. Ma
Department of Engineering Science and Mechanics
The Pennsylvania State University
University Park, PA 16802

At millimeter wavelengths it is necessary to model in detail the geometry, orientation and statistics of the inclusion or discrete phase in a random medium. Previous calculations for the coherent and incoherent fields using the T-matrix to model the inclusion response used spherical statistics even for non-spherical scatterers. This is unrealistic for large volume fractions $c > 0.15$. Values of the pair distribution function for aligned and randomly oriented spheroids obtained with Monte Carlo simulation are used in the multiple scattering calculations. The new results are compared with old results using spherical statistics.

INTERPRETATION OF BACKSCATTER CROSS SECTIONS FOR NORMAL INCIDENCE USING UNIFIED AND TWO-SCALE FULL WAVE ANALYSES OF ROUGH SURFACES

E. Bahar, Electrical Engineering Department
University of Nebraska-Lincoln NE 68588-0511
D.E. Barrick, Ocean Surface Research, Boulder CO 80303
M.A. Fitzwater, Electrical Engineering Department
University of Nebraska-Lincoln NE 68588-0511

A specific and important application of rough-surface scattering at normal incidence concerns short-pulse satellite microwave altimeter return from the sea surface. In addition to its use to measure ocean waveheight at nadir as on Seasat, the altimeter has also been employed to infer wind speed from the backscattered signal intensity, since the roughness statistics depend strongly on surface wind. Up to now, attempts to establish a quantitative connection between altimeter nadir backscattered cross section (per projected area) and wind speed have employed a physical-optics derived specular-point model that (i) relates the backscatter cross section to rms surface slopes, and subsequently (ii) relates surface slopes to wind speed in some manner. Unfortunately, the returns predicted thereby are several dB greater than the measured, leading to use of empirical rather than theory-based models to establish the connection. This discrepancy can only be due to the inadequacy of the simple, specular-point model, as it has been used, to describe the backscattered return even from a gently sloping sea at normal incidence.

The full wave solution for rough-surface scattering reduces to an integral similar in form to the physical optics or perturbation solutions (E. Bahar, Radio Science, 16, No. 3, 331-341, 1981). In its derivation from the exact telegraphists' equations, multiple scattering is neglected. The full wave solution has been shown to reduce to the specular-point result in the high frequency limit, and to the perturbational result (with the correct polarization dependence) in the low frequency limit. Since it is valid across the spectrum for all roughness scales, it is not necessary to adopt the two-scale model to analyze rough surface scattering problems (E. Bahar and M. A. Fitzwater, IEEE Trans. Antennas and Prop. AP-32, No. 7, 730-734, 1984). In recent work however, (E. Bahar and D. E. Barrick, Radio Science, 18, No. 2, 129-137, 1983), the full wave solution has been artificially decomposed into two components to elucidate the mechanisms at play in the two-scale models discussed above.

PASSIVE REMOTE SENSING OF TERRAIN WITH A DENSE DISTRIBUTION OF PARTICLES

Leung Tsang
Department of Electrical Engineering
University of Washington
Seattle, Washington 98195

Passive remote sensing has been applied to terrain media where particles are densely distributed. The radiative transfer equation, in its classical form, has been commonly used to study the volume scattering effects of these problems. However, it has been demonstrated, both experimentally and theoretically, that independent scattering is not true in media with a dense distribution of particles, and the classical radiative transfer equation is not valid.

Recently, a set of "new" transfer equations has been derived from analytic wave theory for dense media. The differences between the "new" set of transfer equations and the classical ones will be discussed. The new equations still preserve the advantages that (i) multiple scattering of the incoherent intensities are included, (ii) energy conservation is satisfied, and (iii) numerical solutions are tractable. Numerical results of the brightness temperatures based on the theory will be illustrated using the physical parameters of the terrain media.

COMMUNICATION IN A THREE ROUGH LAYERED CONDUCTING MEDIA

SAMIRA T. BISHAY

Department of Mathematics, Faculty of Science
Ain-Shams University, Abbassia, Cairo- Egypt.

The problem of communication in the sea has been considered by many authors. Some of them regarded the sea as a two-layered media (air-sea water), the bottom of the sea has not been included. However, the effect of the sea bottom cannot be neglected in some cases. Thus, other authors ascertained theoretically the importance of the sea bottom on radio wave propagation, in certain situations, and considered the sea as a three layered media (air-sea water-ground). Recently, the effect of the variations which occur in the upper surface of the sea, due to sea waves, was investigated. The part of sea under investigation was taken to be of finite depth and the surface of the sea bottom was assumed to be invariable. In this work, the problem of communication in the sea has been considered in terms of a three layered media. The variations which may occur in the shape of both the lower and upper surfaces, due to sea waves, are also taken into consideration. The effect of these variations is studied using the perturbation method. The results obtained are compared with those mentioned elsewhere.

GENERAL RECIPROCITY AND SYMMETRY RELATIONSHIPS FOR THE POLARIZED RADIATIVE FIELD IN PLANE-PARALLEL MEDIA

Ali M. Khounsary, Hyo J. Eom, and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Enginnering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

ABSTRACT

A Green's matrix formulation of the problem of polarized radiative transfer in inhomogeneous plane-parallel media with anisotropic scattering is developed. This procedure leads to the introduction of a fundamental source matrix which is the response of a medium to an imbedded unidirectional, unitary polarized probe. Depending on whether the source and the observation points are located in the interior or on the boundaries of a medium, four sets of scattering matrices in terms of the diffuse vector fields are defined. The fourth set, which corresponds to the case in which both the source and observation points are on the boundaries, is analogous to Chandrasekhar's scattering matrices (for the standard problem).

The reciprocity and symmetry properties of the single scattering process, in conjunction with a method of parametric differentiation are then used to obtain a series of reciprocity and symmetry relationships governing the above scattering matrices. These relationships greatly facilitate the theoretical development, and reduce the computational expenses of evaluating the polarized radiative fields in inhomogeneous anisotropic scattering media.

In view of the linearity of radiative transfer, the Green's matrix approach in conjunction with the superpositon principle allows the evaluation of both the emergent and the internal polarized radiative fields in inhomogeneous plane-parallel media with arbitrary internal and/or external source(s). The scattering matrices can be evaluated through an adding-doubling scheme, although the method of parametric differentiation offers a more direct, but slower alternative.

Evaluation of the total (transmitted, reflected, & internal) polarized field of an inhomogeneous scattering medium is fundamental for many passive and active remote sensing problems at various wavelengths within the meter-to sub-millimeter spectral regions. These include, for example, vegetative canopies with discontinuous underlayer(s). Specfic problems are isolated and solution approaches are discussed.

DEFINITION AND INTERPRETATION OF S-MATRIX FOR DISTRIBUTED METEOROLOGICAL TARGETS MEASURED BY COHERENT POLARIMETRIC RADARS.

M. Chandra A. Schroth E. Lüneburg

DFVLR, Institut für HF-Technik, 8031 Wessling, West Germany

The polarimetric theory available in open literature to-date emphasis primarily the polarimetric interpretation and evaluation of radar measured s-matrix of fixed i.e. coherent targets.

The application of such techniques, however, in distributed meteorological targets (say due to measurements by polarimetric weather radar), such as rain tec., remains, as yet, unclear. The main cause of this 'gap', we believe, lies in the lack of investigations of the following key aspects:

(i) The basis and the definition of the backscatter s-matrix of randomly distributed targets such as meteorological precipitations (in stationary random equilibrium).

(ii) The vital link between the elements of the measured s-matrix and the microphysical properties of the ensemble of scatterers constituting the distributed target. These micorphysical properties refer to the size, shape and orientation spectrum and the scattering amplitudes of the constituent particles in the seatter volume.

Our paper will address these two outstanding aspects. We would thus outline the interpretation of the individual s-matrix elements, for a distributed target, in terms of the microphysical properties of the scatterers. In doing so we would use the conceptual resource already available in the formalism of the coherency matrix and the 4 x 4 Müller's matrix.

Furthermore using well-known drop-size distribution and the scattering amplitude calculation of raindrops (from the T-matrix method) we would theoretically obtain the s-matrix of rain precipitation to illustrate our technique. The polarimetric interpretation (i.e. the description of the Huynen-fork) would then follow. Indeed the dependence ot the s-matrix (for rain target) on the drop-size distribution, thermodynamic phase and orientation of the scatterers (depending on the time available to the authors) would also be investigated and described.

SALON 10
F-3—MOBILE RADIO, REFRACTION, AND MULTIPATH
Chairman: W.J. Vogel
WEDNESDAY-PM

REVIEW OF U.S. PAPERS ON MEASUREMENT OF REFRACTIVITY PROFILES

Robert Joseph Taylor
Johns Hopkins University Applied Physics Laboratory

Ninety papers and reports on measurement of refractivity profiles in the atmosphere were identified and reviewed. These papers and reports were principally from U.S. researchers working during the last 20 years. These papers and reports covered the following subtopics: radiosondes; refractometers; radars; microwave radiometry; acoustic sounders; comparisons of radars, lidars, acoustic sounders; sounding systems; satellite measurements; evaporation ducts; structure function parameters; and refractivity data bases.

A significant number of papers describe problems associated with the present operational method (radiosondes) that is used to measure refractivity profiles. Many believe the present use of radiosondes to measure refractivity profiles is highly questionable for use in RF propagation prediction. Such measurements may be sufficient when the refractivity gradients do not exceed the measurement capability of radiosondes. But one cannot assess beforehand when radiosondes are sufficient without first measuring the actual gradients with better instrumentation. Thus this circular problem logically requires that better instrumentation be used all the time and that radiosonde measurements not be use for RF propagation prediction.

Microwave refractometers have sufficient frequency response and resolution to measure a significant fraction of the potential refractivity gradients which exist in the atmosphere. The best method for their use probably is to include them as sensors on airplanes and to measure the refractivity profile along the flight path of the aircraft.

Radars hold promise for measurement of the refractivity gradient. This potential technique could provide a continuous monitoring of the refraction profile over properly instrumented ships and land stations. Although microwave radiometry does not provide the required resolution of the temperature and humidity profiles, it might be effectively used to determine horizontal gradients of the refractivity in various directions from the prime profile determined by radar or refractometers. Satellites could give a broad overview of the horizontal extent of refractivity conditions. Thus various measurement methods when used together can complement each other and give a compatible and comprehensive description of the spatial and temporal evolution of the refractivity conditions.

A MODEL FOR UHF COHERENT AND INCOHERENT FIELD INTENSITIES IN SUBURBAN MOBILE RADIO

Richard L. Campbell
Department of Electrical Engineering
Michigan Technological University
Houghton, Michigan 49931

Ward J. Helms
Department of Electrical Engineering
University of Washington
Seattle, Washington 98195

If a suburban area is illuminated by a CW source, the field at each point in the region may be obtained by summing the direct wave, a ground reflected wave, and a diffuse component due to reflections from objects in the suburban area. The average coherent intensity is obtained from the vector sum of the direct and specular ground reflected waves, with possible attenuation due to scattering. The coherent intensity model is compared with measurements of the coherent component of horizontally polarized signals in residential Seattle using the assumptions that attenuation due to scattering is low and the direct and ground reflected components are equal.

The diffuse field intensity has been modeled in the past by assuming N horizontally travelling waves arriving at the receiver from all directions. If single scattering is assumed, with scatterers illuminated by the coherent wave, then the nearby, elevated scatterers will be most important. The intensity of the diffuse component will then be a function of the angular distribution of scatterers around the receiver. The model for the diffuse component, using the distribution of buildings along residential streets, is compared with measurements of the distribution of signal arrival angles in residential Seattle.

METEOROLOGICAL STUDIES OF RADAR DUCTING PHENOMENA

Steven M. Babin and John R. Rowland
Applied Physics Laboratory
The Johns Hopkins University
Johns Hopkins Road
Laurel, Maryland 20707

This paper presents the results of radar ducting studies using a 3 GHz (S-band) radar and a 5 GHz (C-band) radar at Wallops Island, Virginia, during May and August of 1985. Helicopter acquired meteorological measurements were made over the ocean while the helicopter was tracked with the aid of C and S-band transponders mounted on the aircraft. Temperature, relative humidity, and atmospheric pressure were measured by sensors located in a ventillated probe mounted beneath the helicopter. Altitude was measured with a radar altimeter. The helicopter made soundings by flying a sawtooth trajectory from an altitude of 3 m to a maximum of 1.5 km. Modified refractivity versus altitude was plotted to locate regions where radar ducting could occur. The helicopter measurements were correlated with the S-band radar backscatter returns from clear air phenomena and sea surface returns caused by ducting. The meteorological measurements were also correlated with quantitative amplitude data received from the C- and S-band transponders. A large number of soundings showed evidence of radar ducting. Helicopter acquired meteorological measurements are shown to be very useful in understanding low level radar ducting phenomena.

LOW-ANGLE MULTIPATH ERRORS

Timothy Griesser and Constantine A. Balanis
Department of Electrical and Computer Engineering
Arizona State University
Tempe, AZ 85287

Radar systems experience significant difficulties when tracking low altitude targets over the ocean because of multipath effects. Reflection off the ocean surface provides an alternate path of travel for the radar echo, as if a target image existed below the water surface. If the radar beamwidth is not sufficiently narrow, the radar will not be able to resolve the target from its image, and it will track a false target whose position can fluctuate widely above and below the actual target position. The radar system, under such conditions, will frequently lose track of the target.

The tracking error due to the multipath phenomenon was analyzed using mathematical models for a monopulse radar system. Computational algorithms have been constructed for both smooth and rough reflection models of the earth interface to illustrate the loss in tracking accuracy whenever the radar system is unable to separate the returned echoes from the target and its image. Targets at ranges of up to 12,000 feet and at altitudes of 5 to 35 feet above sea water have been investigated. Antenna 3-dB beamwidths of 0.9 and 0.25 at 9 GHz and 35 GHz, respectively, were considered. The calculations included provisions for antenna polarizations and sidelobes, as well as divergence factors to account for the curvature of the earth surface.

Computer demonstrations using the smooth surface model, which are valid when the Rayleigh criterion is satisfied, predict undesirable tracking behavior in which the radar boresight frequently comes to equilibrium in a direction far away from the actual target position. This model, being strictly deterministic, can specify uniquely the tracking error as a function of the positions of the target and the radar relative to the earth's surface. Equilibrium points located using the smooth surface analysis were found to be either stable or unstable. The stable points reveal directions toward which the antenna will rotate, while the unstable points represent directions away from which the antenna would turn if it was slightly displaced from equilibrium. The location of stable and unstable points becomes particularly important in determining if the antenna will track the target with its main beam or with one of its sidelobes.

Simulations using the rough surface model are inherently indeterminate and must be analyzed using stochastic models of the ocean surface. With this model, the rough surface theory introduces a band of possible equilibrium directions within which the antenna boresight is expected to lie.

TREE ATTENUATION STATISTICS AT 869 MHz DERIVED FROM HELICOPTER-MOBILE VEHICLE MEASUREMENTS

Julius Goldhirsh and John R. Rowland
Applied Physics Laboratory
The Johns Hopkins University
Johns Hopkins Road, Laurel, Maryland 20707

Wolfhard J. Vogel and Geoffrey W. Torrence
Electrical Engineering Research Laboratory
The University of Texas at Austin, Austin, Texas 07558

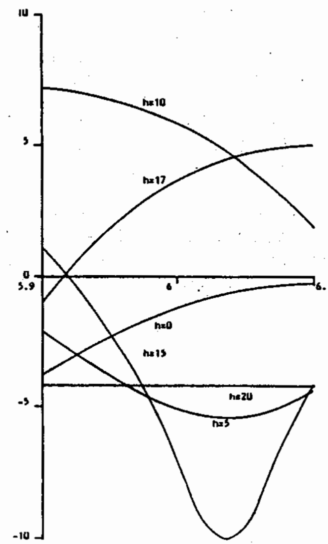
With the advent of planned communications systems between moving vehicles and geostationary satellites, i.e., Mobile Satellite Systems, a paucity of information still exists as to the degradation effects of trees intersecting earth-satellite paths. A week long experiment was conducted in October of 1985 in the Maryland area to address this question.

Helical antennas transmitting a CW beacon level at 870 MHz at right hand circular polarization were mounted on a Bell Jet helicopter. In one mode of operation, the helicopter flew at constant height at fixed elevation angles and near parallel to a moving van containing receiving and data acquisition equipment. The van traveled along highways as well as along country type roads, where in all cases the roads were, in general, lined with trees of the deciduous variety which contained approximately 80% of its foliage. A body of attenuation statistics have been developed which characterizes the effects of elevation angle to the satellite, side of the road driving, and road type. It is apparent that the occurrence of tree attenuation for the stated geometry is influenced markedly by right side or left side of the road driving as well as elevation angle to the satellite. For example, where the elevation angles were approximately 30° and the vehicle was located on the right side of the road nearest the trees through which the propagation path passed through, peak tree attenuation levels were measured (averaged over one second) ranging from 10 to 20 dB. In another mode of operation, the attenuation effects of various tree types were examined for the case in which the van was stationary and located behind the particular tree being examined. The helicopter flew by on one side of the tree at fixed heights, while the van was positioned on the other side. By comparing the measured signal levels for the case in which the propagation path passed through a particular tree with those measured with the van in front of the tree, the attenuation effects as a function of elevation angle were derived. As an example of such a measurement, a bare deciduous sassafras tree showed a peak attenuation of 10 dB (1 second average) for the case in which the van was located 4.3 m away and the signal path was at an elevation angle of 30°, with the tree height being approximately 10 m.

A MODEL FOR MULTIPATH PROPAGATION

H.N.Kheirallah, Dept. of Elec. Eng., Qatar Univ., Doha, Qatar,
H.M.Rashwan and A.K.Aboul-Saoud, Dept. of Elec. Eng., Alexandria Univ., Alexandria, Egypt.

This paper presents a modified version of Ruthroff's multipath model(BSTJ,50,2375-2398,Sept. 1971)in which most of its earlier limitations have been overcome. Although flat earth is still being assumed, the simple mathematical expressions permit a quick investigation of the propagation phenomena under several anomalous conditions. Between two limits of layer heights, the model predicts the presence of two refracted rays in addition to the direct one. Both refracted rays have negative differential path delays with respect to the direct ray. The incorporation of an antenna beam angle discrimination results in the amplitude of the upper ray being smaller than that of the lower ray in most of the cases. The amplitudes of both refracted rays esceed that of the direct ray as the layer height approaches its maximum limit. The model permits the analysis of both frequency and space diversity improvements. A typical numerical example is shown in figure indicating that the closer the layer to the antennas the larger is the dependence of the fading on the antennas separation. Sensitivity analysis of the fading to variations in the propagation medium can also be performed.



Fade level (dB) vs. frequency (GHz). Path length=40Km,gradient below the layer=-40 N units/Km,gradient within the layer=-300 N units/Km,layer height above lower antenna=20m, transmit and receive antennas separation h=0,5,10,15,17 and 20m.

ALIGNMENT AND TRANSMISSION MEASUREMENTS OF QUASI-OPTICAL MILLIMETER WAVE SYSTEMS

Charles E. Mayer
Electrical Engineering Research Laboratory
The University of Texas at Austin

Quasi-optical or open structure receivers have become the best performers in the millimeter wave regime due to the non lossy nature of open air propagation. Separate components are used to collimate, guide, diplex, filter, and converge the millimeter waves on their typical journey from the receiving antenna to the feed horn. Each of these components is allowed five degrees of freedom of movement. Thus the rapid growth of the alignment search space demands a systematic approach.

An alignment sequence and technique are presented here to allow full realization of a receiver's design expectations. Paramount to this technique are two constant power noise sources, namely, blackbody radiators at ambient and liquid nitrogen temperatures. A concentric geometry of the two radiators allow receiver coupling to be calculated versus solid angle of the beam. A different concentric geometry allows the intensity distribution (probably Gaussian) of the collimated beam to be measured. Using this technique, a beam profile can be mapped from the feed horn through the entire quasi-optics system, thereby dictating alignment corrections. Further, power conservation calculations allow subsystem transmission measurements to be obtained. The surface finish requirement of reflectors necessary to prevent scattering losses can easily be experimentally quantified.

A set of measurements is presented showing the alignment and transmission of a 240 GHz quasi-optical receiver. Included in these optics is an error compensating secondary mirror in use with the University of Texas 5-m millimeter wave telescope.

PREDICTION OF WIDE-BANDWIDTH TIME-DOMAIN RADIO TRANSMISSION LOSS OVER IRREGULAR TERRAIN

Raymond J. Luebbers and William A. Foose
Communications and Space Sciences Laboratory
Electrical Engineering Department
The Pennsylvania State University
University Park, Pennsylvania 16802

Methods for predicting the effects of terrain on the propagation of narrow band radio waves have been under development for many years. In the frequency range of 100 MHz to 10 GHz reflection and diffraction are the dominant mechanisms of interaction between radio waves and terrain, and several different propagation prediction models are available for computing narrow-band path loss over irregular terrain.

Due to the use of spread spectrum techniques in tactical communication systems, interest in the effects of terrain on wideband signals has increased. However, most current narrow-band propagation models are not applicable to wideband signals (P. F. Sass, IEEE Trans. Veh. Tech., No. 2, May 1983). One exception is a propagation model based on the Geometrical Theory of Diffraction which approximates the terrain profile as piecewise-linear and utilizes wedge diffraction to compute reflection and diffraction effects. Results obtained with the GTD model have been compared with narrowband measurements for a variety of frequencies and terrain types, and the good agreement obtained has been reported (e.g. R. J. Luebbers, IEEE Trans. Ant. Prop., Vol. AP-32, No. 9, Sep 1984).

Using the narrowband GTD model as a starting point, a wideband terrain-sensitive model is being developed which is capable of predicting the band-limited impulse response of a radio channel including terrain effects. The path loss computations are performed in the frequency domain using the GTD, with the Fast Fourier Transform then used to produce the corresponding time domain results. Predictions obtained using this model are compared with wideband (up to 250 MHz clock rate) time-domain measurements obtained by the Stanford Research Institute, and illustrate the validity and usefulness of the GTD in prediction of terrain effects on wideband radio propagation.

PROPAGATION MODELING FOR LAND MOBILE SATELLITE COMMUNICATIONS

W.T. Smith
W.L. Stutzman
Virginia Polytechnic Institute and State University
Electrical Engineering Department
Satellite Communications Group
Blacksburg, VA 24061

The signal margin for planned land mobile satellite communication systems will be relatively small. Therefore, attenuation due to propagation effects can have a significant impact. Primary among these is vegetative shadowing and secondarily, multipath fading.

In this paper we present results of a study on the modeling of vegetative shadowing and multipath fading. A combined statistical distribution function is derived to evaluate the fraction of time that signal levels are expected to occur. This, in turn, is related to the environment of the mobile and the satellite link parameters. The model is useful in estimating the fraction of time that attenuation levels are encountered for a variety of vegetations, highways, and locations.

WYNDHAM C
F-4—RADAR METEOROLOGY AND OCEANOGRAPHY

Chairman: J. Goldhirsh

THURSDAY-AM

HF RADAR MEASUREMENT OF SURFACE CIRCULATION IN DELAWARE BAY

B. J. Lipa and D. E. Barrick
Ocean Surface Research, Woodside, CA 94062

We describe results of a study of surface circulation in Delaware Bay, Fall 1984. This study is based on two-dimensional current velocity maps measured by an HF radar remote sensing system (Codar) every 1.5 hours over a period of a month. The flow in this bay is strongly dominated by semi-diurnal tides and outflow from the north but varies due to winds and waves generated by storms. The rapidly changing depth along with the enclosing, irregular coastline adds to the complexity of circulation. Tidal coefficients are computed over the map and results correlated with location and bottom topography. Tidal components are then subtracted from the current velocities and the residuals correlated with wind velocities and surface runoff. The use of these results to understand circulation in such complex, enclosed areas is discussed.

A SIMPLE RADAR BACKSCATTER MODEL FOR NEAR GRAZING SEA

Hyo J. Eom, Jonas Okeke and Wolfgang-M. Boerner
Communications Laboratory, SEL-4210
Department of Electrical Engineering & Computer Science (m/c 154)
University of Illinois at Chicago
Chicago, IL 60680-4348

ABSTRACT

A simple backscattering model is proposed for the interpretation of like-polarized radar backscatter behavior near grazing sea from the L band to the sub-mm wavelength regimes. It is assumed that sea waves under high sea wind have both breaking-wave components and water sprays associated with white caps. The proposed radar backscatter formulation models the breaking wave as a perfectly conducting wedge and the water sprays as a random layer embedded with small dielectric spheres. The total radar backscatter is then the sum of wedge-diffracting fields and incoherent return from a Mie or Rayleigh random layer. The proposed model is tested against existing experimental data collected for various sea conditions, frequency, polarization, and grazing angle. It is found that a certain type of radar backscattering behavior near grazing angle can be satisfactorily explained with the proposed simple approach.

THE MAPPING OF DYNAMIC TOPOGRAPHY IN THE SOUTHERN OCEANS USING ALTIMETER DATA

Ella B. Dobson
The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, Maryland 20707

The altimeter is presently the only satellite-borne instrument which shows promise in measuring dynamic topography globally over the worlds oceans. Many research efforts have demonstrated that mapping and time histories of currents and eddies can be extracted from the altimeter signal. Most of these results, with a few exceptions, have reported work in the North Atlantic. This paper presents the results of expanding these type studies to an area of the world's oceans where very little data has been available in the past. Maps of a region off the coast of South Africa indicate a strong correlation between the altimeter height signature (height variability) and the general position of the Agulhas current region. A discussion of altimeter mapping of this current system and its associated eddies is discussed along with an evaluation of the relationship between current flow strength and the ability of the altimeter to make the measurement. That is, given our knowledge of current velocity in this region, what is the required height signal to noise necessary to detect the current or eddy. In addition, some attention is given to the various methods of extracting dynamic topography signals in regions such as the Southern Oceans where no good geoid is available.

STUDIES OF THE LINEARITY OF THE RELATIONSHIP BETWEEN LONG OCEAN WAVES AND THEIR MICROWAVE REFLECTIVITY MODULATION

D.E. Weissman
Hofstra University
Hempstead, NY 11550

W.C. Keller and W.J. Plant
U.S. Naval Research Laboratory
Washington, D.C. 20375

Many of the applications of radar remote sensing to the measurement of ocean wave spectra employ the assumption that a linear transformation relates this "input" to the reflectivity variations at the "output". Experimental microwave radar and environmental data have been analyzed to study this relationship. The measurements of the coherence function, the radar backscatter spectrum and long wave spectrum indicate the simple one-variable transfer function model is not justified. However the departure from this simple model can be explained in terms of additional wind speed and environmental forces, that are consistent with linear system behavior. A unified two-dimensional model for the radar backscatter as a function of the wave slope and wind speed provides consistent interpretations for the behavior of the average radar cross section and the modulation transfer function. For the purposes of airborne and spaceborne remote sensing, a generalized definition of the modulation transfer function is defined and its linearity properties are analyzed with X-band radar data. Also the statistical properties of the "input" and "output" signals have been analyzed to evaluate the linearity of this relationship.

USE OF SYNTHETIC-APERTURE RADARS FOR MEASUREMENT OF PRECIPITATION

R.K. Moore
Radar Systems and Remote Sensing Laboratory
The University of Kansas Center for Research, Inc.
Lawrence, Kansas 66045
and
D. Atlas
Department of Meteorology
University of Maryland
College Park, MD 20742

The use of radars measuring backscatter from rain drops to estimate precipitation rates is well established. To observe relatively small precipitation cells at long ranges requires antennas that are so large that they are difficult to carry on aircraft or spacecraft, so use of synthetic-aperture methods is suggested.

Because of the random motions of raindrops in the turbulent atmosphere, the received signal has a Doppler-shifted spectral width set by the drop velocity distribution. This target motion can therefore result in degraded performance of a synthetic-aperture radar (SAR).

Here it is shown that significant azimuth-resolution improvements can be achieved for spaceborne SARs for all reasonable drop velocities, although the pixel width achieved is far greater than that for stationary targets. For airborne SARs, only the lowest drop velocities result in improved resolutions over those of non-coherent radars. The power required for a SAR is, as for stationary targets, independent of the azimuth resolution.

Calculations are given to shown how a test of this concept for spaceborne radars may be conducted using the SIR-C C-band radar planned for flight near the end of the decade. To achieve adequate resolution in the vertical plane, the SIR-C would have to be operated with the long antenna direction in the vertical plane, resulting in sizeable ambiguities in azimuth. Careful selection of target storms that are sufficiently isolated should allow the test to proceed, although an operational space meteorological SAR would require a wider antenna. The test could also be performed with the radar looking near vertical without the ambiguity problem. The sensitivity of the system is such that rain at rates below 0.2 mm/hr. would be detectable.

Consideration of Platform Motion in CODAR (HF Radar) Remote Sensing of Ocean Surface Conditions

Donald E. Barrick   Belinda J. Lipa
Ocean Surface Research
1131 Cranbrook Court   165 Harcross Road
Boulder, CO 80303   Woodside, CA 94062

Compact HF radar systems called CODARs are presently in operation from offshore oil rigs for real-time mapping of ocean surface currents and monitoring of the waveheight directional spectrum. Based on backscatter from the surface waves, the system derives its information from the Doppler spectrum of the echo signal. In certain cases, these systems must operate from semi-submersibles, which float at anchor and move in response to the longer period ocean waves. The rig-induced horizontal motions of the antenna will produce Doppler shifts in the same general region of the signal spectrum where the current and wave information lie. Hence, their effect on information extraction is assessed, and methods developed that compensate for and remove motion contaminations.

Simulations show that very long-period motions (greater than 50 s) do not appreciably contaminate extraction of currents from the first-order peak in the spectrum; rather, they produce gaps in the angular coverage of the resulting current maps. The shorter, wave-following motions with periods ~10 s produce lower-amplitude phase modulation sidebands lying outside and below the first-order peak region. However, these motion-induced peaks fall precisely on top of the second-order Doppler sidebands that are inverted to give the waveheight directional spectrum. Use of the expressions for second-order scatter from the sea shows that the motion sidebands, if ignored, can produce biases up to ~25% in energy, tending to overpredict sea waveheight by ~12%. We therefore develop and demonstrate methods for measuring the horizontal platform motions with an accelerometer, simultaneously with the sea echo, and removing their Doppler contamination from the averaged, second-order cross spectra before inverting. Examples of these effects based on measured data are shown.

DUAL FREQUENCY, DUAL POLARIZATION BACKSCATTER MEASUREMENTS OF RAIN

K.A. Clark, J.D. Kelly, M.E. Lavelle, J.D. Nespor
Boeing Aerospace Company M/S 8H-51
P.O. Box 3999, Seattle, WA 98124-2499

There has been a great deal of interest in the response of radar systems to rain. Radar backscatter from rain is of particular interest to radar analysts because of the impact it has on detection and tracking of targets, and to the radar meteorologist as a means for measuring relevant storm parameters. Most of the radar backscatter efforts to date have only concerned the amplitude coefficients of the backscatter matrix for frequencies of X-band and below. Recently, much interest has developed concerning backscatter in the MMW region and in obtaining the relative backscatter matrix of rain. The present study addresses the measurement of the complete relative backscatter matrix for rain based upon measurements employing dual frequency, dual polarized coherent radars of X-band (8.9 GHz) and Q-band (45 GHz). In this regard, the experiment was conducted so that the backscatter matrix could be determined on a pulse-to-pulse (X-band) and sweep-to-sweep (Q-band) basis. The results from the measurements are presented in a variety of ways. These include the statistics of the backscatter matrix coefficients versus rain rate, co-polarization null distributions and Mueller matrix parameters for three rain rates. Decorrelation times based upon the complex auto-correlation function, as well as, the auto-covariance are compared. Typical Doppler spectra and cross-spectra of the backscatter returns are presented, and conclusions from this study are presented.

C-BAND DUAL LINEAR POLARIZATION RADARS AND RAIN INDUCED ATTENUATION

K. Aydin, T. A. Seliga and Y. Zhao
Communications and Space Sciences Laboratory
Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802

Radiowaves at C-band (4-6 GHz) can experience significant attenuation in rain. Therefore, data obtained from C-band meteorological radars that perform dual linear polarization measurements should be corrected for the rain induced attenuation effects. The true reflectivity factor at a certain gate can be recovered by determining the two way attenuation up to that gate. On the other hand, the true differential reflectivity at the same gate can be obtained by compensating for the two way differential attenuation between the H and V polarizations up to that gate. This paper presents a procedure enabling dual polarization C-band data to be corrected for attenuation and differential attenuation caused by rain. This is accomplished by making use of only C-band data itself. Simulations of radar measurements from disdrometer data are used to demonstrate the procedure which may be applied at other attenuating wavelengths as well.

RADAR REMOTE SENSING OF HAIL: COMPARISON OF DUAL POLARIZATION AND DUAL WAVELENGTH TECHNIQUES

T. A. Seliga and K. Aydin
Communications and Space Science Laboratory
Department of Electrical Engineering
The Pennsylvania State University
University Park, PA 16802

V. Balaji
Convective Storms Division
National Center for Atmospheric Research
Boulder, CO 80307

Differential reflectivity (Z_{DR}) radar measurements have been used in detecting hail with the results to date being very encouraging. Recently, the authors have defined a new hail signal (H_{DR}) based on the signature of rain on the (Z_H,Z_{DR}) plane. This signature is obtained from disdrometer measurements of raindrop size distributions. It is observed that data for rainfall are clustered in a certain region of the (Z_H,Z_{DR}) plane. Hence, certain (Z_H,Z_{DR}) pairs lying outside this rainfall region are considered to be due to ice phase hydrometeors. This paper focuses on the comparison of the H_{DR} hail signal with the dual wavelength hail signal as described by Tuttle and Rinehart (J. Clim. and Appl. Meteor., 1914-1921, 1983). Hailstorms observed on June 4, 1983 and June 13, 1984 by the CP-2 radar system of NCAR during MAYPOLE'83 and '84 in Colorado are used for this purpose. Ground based confirmations of hail for these storms were obtained by mobile chase teams.

WYNDHAM C
F-5—SENSING THE EARTH'S SURFACE
Chairman: V. Kaupp
THURSDAY–PM

NEAR REAL TIME TERRAIN CLUTTER CROSS SECTION MEASUREMENTS, ANALYSIS AND GRAPHICAL DISPLAY

K.V.N. Rao
John F. Lennon
William G. Stevens
Electromagnetic Sciences Division
Rome Air Development Center
Hanscom AFB, MA 01731

At the previous URSI meetings (K.V.N. Rao, James Coffey, June 1985 URSI meeting at University of British Columbia Vancouver Canada, paper F7-4 and K.V.N. Rao, James Coffey, John Austin, January 1984, URSI meeting at Boulder, CO, paper B2-7) we described the use of a mobile van with a wideband microwave system for measurement of the calibrated backscatter clutter cross section of sandy soil. Since then, we have installed a MASSCOMP 32-bit mini-computer system with a data acquisition and control processor (DACP) in the van.

In this paper we describe two new aspects of our program. The first is the use of the computer system to produce near real time outputs for rapid assessment of the data being generated. The second is the description of analytical models to calculate the backscatter cross section as a function of resolution cell.

In the discussion of near real time aspects we describe the technique of acquiring the inphase and quadrature components of the return signal. We also discuss the use of our customized software packages to transform these data into display outputs of normalized backscatter cross sections as a function of resolution cell. The near real time display of the analyzed data on a video monitor enables us to assess the echo data obtained from the same clutter source either at various intervals of time, or at different look angles. Results of spatial and temporal statistical variations of the scattering are shown.

A brief description is given of the general analytical models designed to calculate the backscatter clutter cross sections. Ground truth parameters determined during the experiment are used in these models to generate the corresponding analytical clutter cross sections. The calculated values are compared with the measured values.

LAVA FLOW TEXTURE FROM SIR-B

Robert W. King[1]
Verne H. Kaupp[1]
William P. Waite[1]
H.C. MacDonald[1]

Lisa Gaddis[2]
Peter Mouginis-Mark[2]

[1] University of Arkansas
Fayetteville, Arkansas 72701

[2] University of Hawaii at Manoa
Honolulu, Hawaii 96822

Abstract

Many geological features such as lava flows have characteristic surface texture variations over their extent. Using SIR-B images of the volcanically active region of the island of Hawaii, we have attempted to employ image processing techiques (such as spatial filtering and convolution) with selected local statistical operators to discriminate the progression from smooth to rough textures for a few known lava flows.

The images provided by SIR-B have a resolution of about 30 meters, but the scale of the textural features of interest is in the centimeter to meter range. The resolution of the imaging device limits the spatial information directly exploitable. However, statistical analyses permit us to discriminate regions of differing surface texture. This paper details our results with the associated images.

RADAR BACKSCATTER MEASUREMENTS ON SOME VEGETATION SAMPLES

L.E. Allan and Y.M.M. Antar
Division of Electrical Engineering
National Research Council of Canada
Ottawa, Ontario, Canada
K1A 0R8

Increased interest has been shown recently in remote sensing of forests by radars. For such an application, the electromagnetic scattering characteristics of tree leaves, branches and trunks are important. Models, in which tree trunks and branches are treated as lossy circular dielectric cylinders and leaves as flat lossy dielectric discs, have been developed. However, there is a lack of experimental results to build confidence in the models. This prompted the present investigation.

A backscattering measurements facility is in operation at NRC in Ottawa, where measurements of the complex backscattering matrix elements at 9.6 GHz on many dielectric man made samples have been done. In the present investigation, measurements are being done on some tree branches and leaves. Obviously it would be very hard in practice to measure every possible type of vegetation, but the data on some would be helpful in developing models. The results on samples tested so far show less oscillations in the backscattering from leaves, as compared to branches. Moreover the scattering characteristic for branches show more sensitivity to shape and size. Preliminary results, and comparison with data on lossless dielectric flat discs and cylinders will be presented.

MICROWAVE BACKSCATTER COEFFICIENTS OF ARTIFICIALLY GROWN FIRST YEAR SEA ICE

D. Xue, R.K. Moore, T.H. Lee Williams
Radar Systems and Remote Sensing Laboratory
The University of Kansas Center for Research
Lawrence, Kansas 66045
and
R. Onstott
Radar Science Laboratory
ERIM
Ann Arbor, Michigan 48107

The radar backscatter coefficient of simulated first year sea ice grown at the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) was measured at 5.2, 9.6, 13.6 and 16.6 GHz, using a dual-antenna FM-CW scatterometer. Measurements were made for calm water, smooth ice and roughened ice with and without a dry snow layer. The scattering coefficient (σ°) values were corrected for antenna separation and antenna beamwidth to yield plots of σ° versus incidence angle. The corrections were made using both a Gaussian approximation to the antenna pattern and using the measured antenna patterns, including side-lobes.

A best fit of the measured scattering coefficients to the physical optics model yielded surface roughness data, confirming that surface scattering is dominant for the first-year ice surface. At incidence angles above 15°, the returns separated into two groups. The snow-covered and rough gray ice show similar angular responses, due to volume scatter and surface scatter, respectively. The remaining surfaces showed a more rapid decrease in return with incidence angle.

SCATTERING FROM A DIELECTRIC DISK WITH AND WITHOUT INHOMOGENEITY

Lin-Kun Wu and Kenneth Demarest
Radar Systems and Remote Sensing Laboratory
University of Kansas Center for Research, Inc.
Lawrence, Kansas 66045

Experimental observations of fine-resolution radar backscatter indicate that leaves are the dominant scatterers for corn and soybean plants at 10 GHz. In previous analyses of scattering properties of individual leaves, they were usually modeled as homogeneous disks. As a leaf's ribs usually have a higher dielectric constant than the leaf surface, a theoretical investigation of the effects of dielectric inhomogeneity on the scattering behavior of a dielectric disk has been needed to determine the significance of the ribs.

In this study, we present a method-of-moments solution to the scattering from a rectangular dielectric disk with and without a centered high-dielectric inhomogeneity. In contrast to the well-defined RCS pattern observed for a homogeneous disk, the RCS pattern of the inhomogeneous disk exhibits shallow nulls and high sidelobes (especially for HH-polarization near grazing incidence). The above observations suggest that the rib has significant effects on the scattering behavior of a leaf and, therefore, should be taken into account while developing detailed backscatter models for vegetation.

FINE-RESOLUTION 10-GHZ RADAR SIGNATURES OF FOUR COMPONENTS OF AN URBAN SCENE:LAWN BRASS, CONCRETE WALKWAY, ASPHALT PAVEMENT AND CURB

R. Zoughi, R.K. Moore and J. Bredow
Radar Systems and Remote Sensing Laboratory
The University of Kansas Center for Research, Inc.
Lawrence, Kansas 66045

A very-fine resolution FM-CW radar system operating at 10 GHz with a range resolution of 11 cm and a footprint of 20 cm in diameter at a range of 4.5 meters, was used to investigate radar backscatter from a site which consisted of a grass lawn to the side of a concrete walk which was connected to an asphalt pavement by a street curb. Measurements were made at incidence angles of 30 and 50 degrees for both vertical and horizontal polarizations. At both angles and polarizations, the smooth concrete walk gave the least backscatter, while backscatter from the grass and the combination of surface and volume scattering from the asphalt gave stronger responses. The backscatter from the curb was quite variable. This may be explained by its nature as a corner reflector.

GEOLOGY OF CENTRAL IRAN

Dr. Mohammad Razani
ITRC, P.O.BOX 14155-3961
Tehran,Iran

Nimbus 5 ESMR observations over the central part ofIran over an eight month period showed consistant results - with the monthly precipitation in this area. This is because of the fact that at ESMR operating frequency, the brightness temperature is highly dependant on the liquid water present on the surface, which has a high dielectric constant at microwave frequencies.

The emissivity of a land surface is typically greater than 0.9, so the brightness temperature contrast between land and water is greater than 100 k. Using this fact,-- the outlines of the continents will be visible in the - Electrically Scanning Microwave Radiometer images.

The moisture content of the soil in areas of little vegetation affects the microwave signature a great deal. It has been observed that the brightness temprature of soil decreases rapidly for soil moisture values greater than 20 percent by weight. In contrast with soil, the - liquid water content of snow seems to increase the radiometric brightness. In general, data received by ESMR will be affected by water vapor, clouds, rain,surface-- winds,soil moisture, snow, and ice cover.

In this paper the north central part of Iran will be studied. The climate,geology, and hydrogeological provinces will be briefly covered. After gaining some familiarity with the characteristics of this part of the country, the Iranian playas,(kavirs), in general and the Great Kavir in specific will be covered. The last part will show how the ESMR data responds to the actual location and characteristics of playas.

EFFECTS OF VEGETATION COVER ON THE MICROWAVE RADIOMETRIC SENSITIVITY TO SOIL MOISTURE

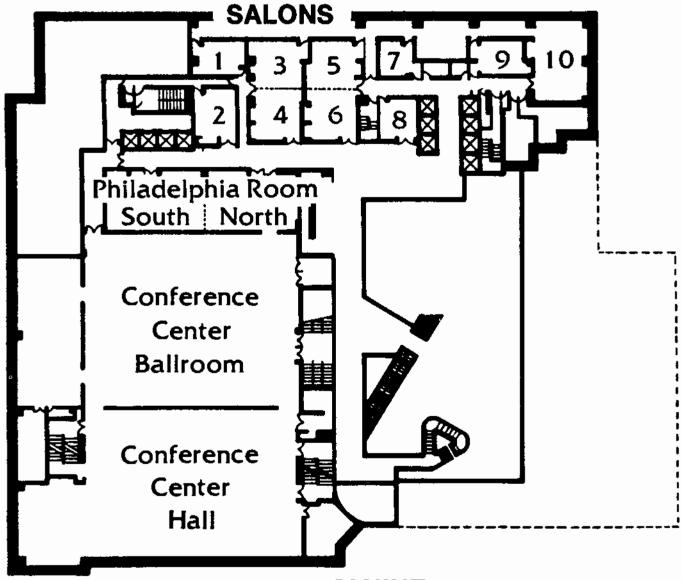
Dr. Mohammad Razani
ITRC, P.O.BOX 14155-3961
Tehran, Iran

The reduction in sensitivity of microwave brightness temprature to soil moisture content due to vegetation cover is analyzed using airborne observations made at 1.4 and 5.0 GHz. The data were acquired during six fligths in 1978 over a test site near Colby,Kansas. The test site consisted of bare soil, -- wheat stubble, and fully mature corn fields.

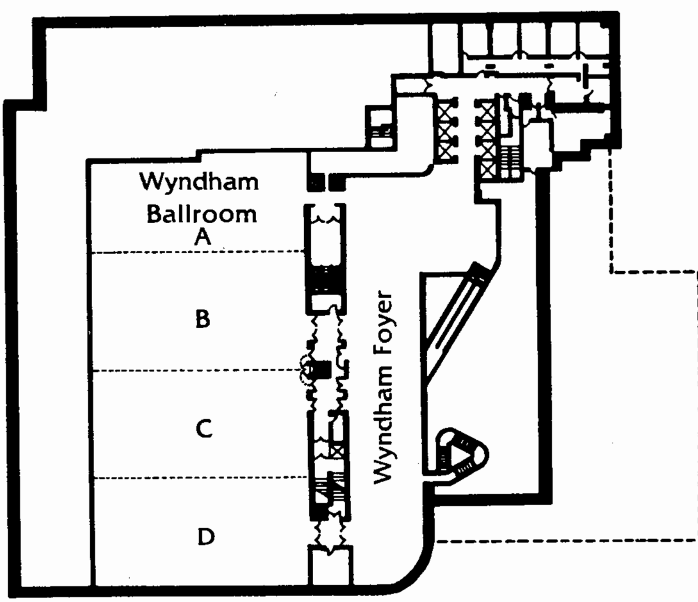
The results for corn indicates that the radiometric sensitivity to soil moisture,S, decreases in magnitude with increasing frequency and with increasing angle of incidence (relative to nadir).

The sensitivity reduction factor, defined in terms of the radiometric sensitivities for bare soil -- and canopy-covered conditions, Y=1-Scan/Ss was found to be equal to 0.65 for normal incidence at 1.4 GHz, and increases to 0.89 at 5 GHz. These results confirm previous conclusions that the presense of vegetation cover may pose a serious problem for soil moisture detection with passive microwave sensors.

AUTHOR INDEX



MEZZANINE



BALLROOM LEVEL