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UNITED STATES NATIONAL COMMITTEE
International Union of Radio Science

U.R.S.I.

National Radio Science Meeting

June 16-19, 1981

Sponsored by USNC/URSI
held jointly with
International Symposium of
Antennas and Propagation Society
Institute of Electrical and Electronics Engineers
Bonaventure
Los Angeles, California
U.S.A.

1981 IEEE/AP-S AND URSI TECHNICAL PROGRAM
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United States National Committee
INTERNATIONAL UNION OF RADIO SCIENCE

PROGRAM AND ABSTRACTS

1981 Spring Meeting
June 16-19

Held Jointly with

ANTENNAS AND PROPAGATION SOCIETY
INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

Los Angeles, California

NOTE:

Programs and Abstracts of the USNC/URSI Meetings are available from:

USNC/URSI
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, DC 20418

at $2 for meetings prior to 1970, $3 for 1971-75 meetings, and $5 for 1976-81 meetings.

The full papers are not published in any collected format; requests for them should be addressed to the authors who may have them published on their own initiative. Please note that these meetings are national and they are not organized by International URSI, nor are the programs available from the International Secretariat.

The 1981 Steering Committee is happy to welcome you to Los Angeles for this IEEE International Symposium on Antennas and Propagation and National Radio Science Meeting. We are pleased to note that the IEEE International Symposium on Microwave Theory and Techniques is being offered cooperatively and concomitantly, with overlapping sessions of mutual interest at mid-week.

Many interesting activities have been planned and we urge you to consult pp. 1-6 of your Advance Program for detailed information. There will be a special session offered by URSI Commission B honoring the late Dr. Georg Goubau and another special session, organized by URSI Commission H, on the subject of Laboratory, Space, and Fusion Plasmas. A Plenary Session jointly sponsored by MTT, AP, and URSI will occupy Wednesday morning and will offer four invited papers on significant topics of current interest.

The social program has been designed to provide you with a cross section of the attractions of the Los Angeles area. A tour of the Pacific Coast will be highlighted by a visit to the Getty Museum. Hollywood at night will feature a drive through the Sunset Strip and a refreshing stop at a beautiful Japanese Garden. There will be a tour of Universal Studios for the movie afficionados. The busy Los Angeles harbor will be viewed from the decks of a pirate ship, complete with buccaneers. A trip to Disneyland is planned, as are tours of central Los Angeles, Pasadena and the Huntington estate. The piece de resistance is the AP/URSI banquet aboard the Queen Mary, preceded by an optional tour of the Queen and an attitude adjustment period on the fan tail deck. We hope that you will be able to attend some of these events.

Companies, institutions, and people too numerous to thank individually have contributed to the organization of this Symposium. The members of the Steering Committee have been generous with their time and energy and I wish to take this opportunity to thank each of them for their contribution to a joint effort that has made it possible for all of us to attend this 1981 International Symposium.

Sincerely,

Bob Elliott

Robert S. Elliott
Chair, Steering Committee

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DESCRIPTION OF THE

INTERNATIONAL UNION OF RADIO SCIENCE

The International Union of Radio Science is one of 18 world scientific unions organized under the International Council of Scientific Unions (ICSU). It is commonly designated as URSI (from its French name, Union Radio Scientifique Internationale). Its aims are (1) to promote the scientific study of radio communications, (2) to aid and organize radio research requiring cooperation on an international scale and to encourage the discussion and publication of the results (3) to facilitate agreement upon common methods of measurement and the standardization of measuring instruments, and (4) to stimulate and to coordinate studies of the scientific aspects of telecommunications using electromagnetic waves, guided and unguided. The International Union itself is an organizational framework to aid in promoting these objectives. The actual technical work is largely done by the National Committees in the various countries.

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The Secretary-General's office and the headquarters of the organization are located at Avenue de Lancaster 32, B-1180 Brussels, Belgium. The Union is supported by contributions (dues) from 36 member countries. Additional funds for symposia and other scientific activities of the Union are provided by ICSU from contributions received for this purpose from UNESCO.

The International Union, as of the XIXth General Assembly held in Helsinki, Finland in August, 1978, has nine bodies called Commissions for centralizing studies in the principal technical fields. The names of the Commissions and their chairmen follow.

A. Electromagnetic Metrology
S. Okamura (Japan)

B. Fields and Waves
L. B. Felsen (USA)

C. Signals and Systems
V. Zima (Czechoslovakia)

D. Physical Electronics
W. G. Farnell (Canada)

E. Electromagnetic Noise and Interference
G. H. Hagn (USA)

F. Wave Phenomena in Non-Ionized Media
A. T. Waterman, Jr. (USA)

G. Ionospheric Radio and Propagation
B. Hultqvist (Sweden)

H. Waves in Plasmas
F. W. Crawford (USA)

J. Radio Astronomy
H. Tanaka (Japan)

Every three years the International Union holds a meeting called the General Assembly, and the next is the XXth, to be held in Washington, D.C., in August, 1981. The Secretariat prepares and distributes the Proceedings of these General Assemblies. The International Union arranges international symposia on specific subjects pertaining to the work of one Commission or to several Commissions, and also cooperates with other Unions in international symposia on subjects of joint interest.

Radio is unique among the fields of scientific work in having a specific adaptability to large-scale international research programs, since many of the phenomena that must be studied are world-wide in extent and yet are in a measure subject to control by experimenters. Exploration of space and the extension of scientific observations to the space environment are dependent on radio for their research. One branch, radio astronomy, involves cosmic phenomena. URSI has in all this a distinct field of usefulness in furnishing a meeting ground for the numerous workers in the manifold aspects of radio research; its meetings and committee activities furnish valuable means of promoting research through exchange of ideas.

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In Memoriam Dr. Georg Goubau

Dr. Georg Goubau, internationlly known scientist, died on October 17, 1980, at 73 years of age. He was born in Munich, Germany, and lived since 1950 in Eatontown, New Jersey.

He studied at the Technical University of Munich where he majored in physics under the guidance of Prof. Zenneck. He earned his MS and PhD degrees in 1930 and 1931; in 1936, he earned the Dr. habilitatus degree. He remained at the Technical University of Munich as an Assistant Professor and Dozent (Associate Professor) until 1939.

Dr. Goubau's field of research during that time was the experimental and theoretical investigation of ionospheric wave propagation. As a first major step in these studies, he designed and installed an ionospheric research station in the vicinity of Munich. It was the first such station in Germany; the station remained in operation until 1949.

In 1939, Dr. Goubau was appointed Full Professor and Director of the Department of Applied Physics at the University of Jena. Here, he lectured on high frequency techniques, electron optics, gas discharges, and measuring techniques; he conducted research on antennas and performed fundamental studies on waveguides, cavities, and microwave circuits. The results of these studies are presented in the book "Elektromagnetische Wellenleiter und Hohlräume," which Prof. Goubau wrote together with his associates during 1947. Due to postwar conditions in Germany, publication was delayed until 1955. The book was translated into English in 1961.

In 1947, Prof. Goubau joined the US Army Signal Corps Engineering Laboratories at Fort Monmouth, N. J. (later to become the US Army Electronics Command Laboratories), where he worked until his retirement in 1973. During this time he conducted research on a wide variety of subjects in the general area of electromagnetics, including unconventional antennas, free-space and guided wave propagation, optical transmission, scatter and diffraction, microwave power transmission, microwave network components, and measurement techniques. He made original contributions to the state-of-the-art in all these fields. Among these contributions, two are outstanding and have become associated with his name: the surface wave transmission line, also known as the Goubau-line; and the beam waveguide, a low-loss lens guide for long distance transmission of coherent optical beams. In the theoretical investigation of these beam waveguides, which he first studied at millimeter wavelength, he developed the now widely-used concept of Gaussian beam modes. His papers on these investigations have become classics.

Dr. Goubau's retirement in 1973 was only nominal. He now investigated fundamental questions in the area of low-profile antennas and new, multielement approaches to their design. For several years he worked as a consultant to the Electronics Command Laboratories, where in 1976 he chaired a Workshop on Electrically Small Antennas which was attended by an international audience.

In 1974, he became a Visiting Professor at Rutgers University, where he joined the faculty of the Electrical Engineering Department working as a thesis advisor. In the course of his work there, he developed a novel computer modeling method for small antennas of complex configuration.

Dr. Goubau was the author of numerous publications and the holder of twelve major patents. His achievements were recognized by many awards including Fellowship to the IEEE, the IEEE Harry Diamond Award, the John T. Bolljahn Award of the IRE Professional Group on Antennas and Propagation, and the highly-esteemed Decoration for Meritorious Civil Service of the Department of the Army.

Dr. Goubau's work was distinguished by unusual creativity and adherence to the highest professional standards. He was uncompromising in his quest for excellence. The question of whether he was primarily a theoretical or an experimental physicist is difficult to answer; he was an expert in both disciplines. His particular strength was an exceptional insight and intuitive understanding of physics. He insisted on exactness in his theoretical work and favored analytical approaches guided throughout by physical reasoning, often resulting in elegant solutions. In his experimental work, he favored techniques which were refined but simple and, hence, highly accurate.

He, himself, was his most demanding critic and liked to clarify his ideas in discussions with his associates. In these discussions, which were both enjoyable and enlightening, he persisted until all aspects of the problem at hand were fully understood. He regarded only significant advancements worthy of publication and used great care in preparing these publications. To those who had the opportunity and good fortune to work with him, he was an inspiring teacher. Several of the students he taught in Germany are now professors; many of his associates in the United States earned their PhD degrees under his stimulating guidance.

Dr. Goubau will be remembered by his friends and colleagues for his integrity, sincerity, sense of humor, and personal concern for his coworkers. Even under the burden of a heavy workload he was perfectly composed; he was easily accessible to everyone who sought his consultation and advice. In his personal approach, Dr. Goubau was direct, sincere, and unassuming. Close relationship with him resulted not only in friendship with him, but in admiration and respect. Dr. Goubau's death is a great loss to his friends and to the scientific community.

Felix Schwering

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Joint IEEE AP-S/MTT-S, URSI PLENARY SESSION
WEDNESDAY 8:30-12:00
CALIFORNIA ROOM

Moderator: Dr. Seymour Cohn
Consultant

1. Dr. P. Napier; National Radio Astronomy Observatory, Socorro, NM
   Topic: The Very Large Array Radio Telescope

2. Dr. S. Okwit; LNR Communications, Inc., Farmingdale, NY
   Topic: Sources of Noise Contribution in Systems

3. Dr. O.P. Gandhi; University of Utah, Salt Lake City, UT
   Topic: Biological Effects and Medical Applications of Electromagnetic Energy

4. Dr. E. C. Stone; JPL and Physics Department, California Institute of Technology, Pasadena, CA
   Topic: The Voyager Encounter with Saturn

SESSION B-1 SCATTERING I
TUESDAY 8:30-12:00
SANTA ANITA, Room B

Chairman: G. A. Thiele
University of Dayton
Dayton, OH

Electromagnetic Scattering by Open Circular Waveguides

T.W. Johnson*

D.L. Moffatt**

Abstract

The electromagnetic backscattering by hollow circular cylinders of both semi-infinite and finite extent are examined in the spectral and temporal domains. In the spectral domain, interest is concentrated in the region D/λ less than 2.0, where D is the diameter of the cylinder. For the semi-infinite cylinder, the Wiener-Hopf factorization functions are evaluated exactly (numerical integration) leading to new results for the radar cross section. These results are also utilized (on axis incidence) to demonstrate the inadequacy of asymptotic approximations when D/λ is less than unity, and that excellent agreement is obtained for D/λ greater than unity. The inadequacy of certain low frequency asymptotic forms for the factorization functions is also demonstrated, including the fact that inclusion of additional terms from the small argument approximation does not improve the result.

The on-axis impulse response of the semi-infinite circular waveguide is obtained by numerical inversion. On axis impulse response waveforms of finite length hollow cylinders with short and open rear terminations are also obtained using numerical inversion of moment method calculations. A comparison of these results suggests that despite the complexity of the exact solutions, simple models based on time domain considerations may prove adequate for low frequency scattering by duct-type configurations. One such model is suggested.

* Air Force Institute of Technology, WPAFB, Ohio

** Electro-Science Laboratory, The Ohio State University.

SCATTERING FROM OPEN CYLINDERS

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The scattering from open cylinders is examined in terms of the electric field integral equation (EFIE). This formulation is solved by the Galerkin technique using three different sets of expansion and testing functions for the orthogonal currents on the scatterer. In these representations, special consideration is given to the boundary conditions imposed by the edges of the structure. The convergence of the foregoing solutions is compared for various cylinder lengths and radii. While these formulations are effective primarily for cylinders in the resonance and intermediate frequency regions, examples are presented for scattering from large cylinders (up to 25 λ in length). The viability of the EFIE formulation for thick-walled cylinders is also discussed. All the foregoing cases are compared with recently obtained experimental data.

*Permanent Address: Department of Physics, University of Missouri at St. Louis, St. Louis, MO 63121.

DIFFRACTION BY A PERFECTLY-CONDUCTING PLANE ANGULAR SECTOR: IMPROVEMENTS ON THE EIGENFUNCTION SOLUTION AND SOME NUMERICAL RESULTS

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University of Thrace
Xanthi, Greece

and

Gary A. Thiele
University of Dayton
Dayton, Ohio 45469

Previous work on the problem of diffraction by a plane angular sector has been with the exact eigenfunction solution, but results have only been presented for the quarter plane. To find the eigenvalues and eigenfunctions of the problem, the continued fraction method is used. In this method it is assumed that the solution has a certain form and that a recurrence relation gives a set of equations. This set relates the coefficients of the eigenfunctions. Furthermore, a determinant can be identified which must be zero to have a non-trivial solution. The determinant's equation can be given in the form of an infinite continued fraction which relates the eigenvalues of the problem.

To use the method above, then, we must determine the form of the solution and determine the eigenvalues by the continued fraction method. However, many times, especially in non-periodic solutions it is not easy to determine the form. Also, the continued fraction method is useless because we need long computation times which become unreasonably long for the larger eigenvalues due to instability in the continued fraction method. In this paper we will describe a method which overcomes all of these difficulties.

Results will be shown for the eigenfunctions and eigenvalues on angular sectors of various shapes (i.e. $0.1 \leq k^2 \leq 0.9$) and results will also be shown for the current distribution and the far field when the angular sector is illuminated by a $\lambda/2$ dipole.

PLANE-WAVE DIFFRACTION BY A WEDGE - A SPECTRAL DOMAIN APPROACH

A. Ciarkowski* and R. Mittra
Department of Electrical Engineering
University of Illinois
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The problem of plane-wave scattering by a perfectly conducting wedge has been investigated by many authors, including Sommerfeld, who obtained an integral representation of the solution many years ago. A GTD solution has been derived by Keller and is expressed in the form

$$u = u^i T_1 + u^r T_2 + u^d \tag{1}$$

where u is the total field, u^i is the incident field, u^r is the reflected field, u^d is the diffracted field, and T_1, T_2 are truncation operators which either equal unity or zero in the appropriate range determined by the observation and incident angles. It is evident that for a given incident angle the first two terms are discontinuous as a function of the observation angle. The discontinuities occur at the shadow boundaries of the incident and GO reflected fields where the GTD diffracted field exhibits a singular behavior. Uniform theories based on various ansatz have been proposed to alleviate this difficulty with the Keller solution, and are widely used in the literature.

The purpose of this paper is to show that starting from the Sommerfeld solution one can derive an alternate representation for the total field which has the form

$$u = u^i + u^s \tag{2a}$$

$$u = u^i + u^{po} + u^f \tag{2b}$$

where u^s is the scattered field which can be expressed as a summation of the physical optics diffracted field u^{po} and the fringe diffracted field u^f. The above representation is similar to the STD solution for the half plane (Mittra, Rahmat-Samii and Ko, Proc. IEEE, 67, 11, 1486-1503, 1979) and may therefore be viewed as the generalization of the half plane solution to the wedge. An important feature of the solution in (2a) is that it is uniform throughout the entire range of the observation angles as both terms in the r.h.s. of (2a) are bounded and continuous. Furthermore, it is shown in the paper that the integral representation for the scattered field u^s can be manipulated such that one can identify the contribution of the physical optics current in the scattered field while the remainder of the integral is associated with the contribution of the fringe current.

*Dr. A. Ciarkowski is on leave from the Institute of Fundamental Technological Research, Electromagnetic Wave Theory Department, Warsaw, Poland.

NEW ASYMPTOTIC WEDGE DIFFRACTION COEFFICIENTS

A.Mohsen.
Faculty of Engineering,Eng.Math.&Phys.
Cairo University,Giza,Egypt.

The diffraction of plane,cylindrical and spherical waves by a perfectly conducting wedge is considered.The resulting diffraction integrals are written as the integrals of the product of an excitation function and a pattern function which decays for large values of the integration variable. Since the asymptotic value is mainly from the neighbourhood of the zero of the integration variable,the resulting expressions have extended ranges of validity.

Usually the accuracy of the deduced asymptotic expressions for cylindrical and spherical wave excitations is not as good as the corresponding plane approximation.The reason is due to the asymptotic expansion which is usually performed for their excitation function prior to the application of stationary phase method.A method here is presented which yields better approximation and in the same time preserves the familiar expressions in terms of Fresnel's integrals.In particular,these expansions give the exact expression on the shadow and reflection boundaries.

The frequent appearance of the Fresnel's integrals in asymptotic diffraction theory and their use at shadow and reflection boundaries,justify seeking a simple approximation for these integrals.A simple rational approximation for these integrals is presented.This approximation gives reasonably accurate values at both small argument,corresponding to shadow boundaries, as well as for large arguments which are encountered in far field analysis.Such a simple approximation may prove to be advantageous in further applications of GTD.

INTERACTION OF A PLANE ELECTROMAGNETIC WAVE WITH A DIELECTRIC BODY: A NEW HYBRID ITERATIVE SOLUTION

R. Bansal, T. T. Wu and R. W. P. King
Gordon McKay Laboratory, Harvard University, Cambridge, MA 02138

The absorption of electromagnetic radiation by dielectric bodies is a problem of current interest because of its application to the study of such phenomena as microwave-attenuation by rain-drops, the biological effects of EM radiation, and the design of miniature dielectric filters. In this paper we present a new approach to the solution of this problem. We have called our method a hybrid solution because it combines the analytical eigenfunction-expansion method with a (single) surface integral equation.

In particular, we have applied our technique to compute the electromagnetic fields inside a finite dielectric cylinder excited by a plane electromagnetic wave. By taking advantage of the fact that the dielectric bodies in the above-mentioned applications are generally characterized by a large relative dielectric constant, we have been able to "decouple" the internal absorption problem from the external scattering problem. For each iteration, we first solve the external problem numerically using a surface integral-equation solution, adapted from a fast moment-method algorithm (J. R. Mautz and R. F. Harrington, Tech. Rept. TR-77-2, Dept. of Electrical and Computer Eng., Syracuse University), and compute the tangential magnetic field $\vec{H}_{tan}$ on the surface of the body. This $\vec{H}_{tan}$ then serves as the boundary condition for an eigenfunction solution of the internal problem. The theoretical results are compared with our measured data on finite dielectric cylinders.

BOUNDARY INTEGRAL EQUATIONS FOR SCATTERING FROM COMPLEX DIELECTRIC STRUCTURES

R. E. Kleinman, Institute of Mathematics,
University of Delaware, Newark, DE 19711
and
N. J. Damaskos and J. R. Jameson, N. J. Damaskos, Inc.
P. O. Box 469, Concordville, PA 19331

Boundary integral equations are derived for the problem of scattering of electromagnetic waves by two-dimensional finite structures consisting of piece-wise homogeneous (possibly complex) dielectric domains. Ensembles of dielectrics, perfect conductors and coated conductors are included in the general formulation as are conductors with successions of layers whose constitutive parameters vary from layer to layer. The boundary integral equations are reduced to a numerical code and computed results for particular structures are presented. Highly complicated scatterers may be handled by reducing the boundaries to a collection of line segments so that only the endpoints and the dielectric constants on either side of the segment need be considered.

REFLECTION FROM GYROELECTROMAGNETIC LAYERED MEDIA

N.J. Damaskos, A.L. Maffett and P.L.E. Uslenghi
NJDI, Box 469, Concordville, PA 19331

A planar structure formed by an arbitrary number of adjacent layers of different materials is considered. Each layer consists of a medium which is linear and homogeneous, but anisotropic; more precisely, the medium is allowed to possess both gyroelectric and gyromagnetic properties. The structure has free space on one side and an isotropic medium (e.g., a dielectric or a metal) on the other side.

The propagation constants and the components of the electric and magnetic fields are determined in each layer. The reflection coefficients are obtained for a primary plane wave which is obliquely incident on the structure from free space. The calculations are implemented via a chain-matrix approach which reduces to that of Collin (Field Theory of Guided Waves, 1960) for the special case of isotropic materials.

Detailed numerical results are presented for the reflection coefficient as a function of angle of incidence and of polarization of the primary wave, for several combinations of gyroelectric, gyromagnetic, uniaxial and isotropic layers. Possible applications of the obtained results are discussed.

HIGH FREQUENCY DIFFRACTION FROM A STRIP IN A FLAT PLANE WITH ARBITRARY IMPECENCE BOUNDARY CONDITIONS

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University of Florence
Florence, Italy

High frequency asymptotic expressions are derived for the far field scattered by a strip in a flat plane where arbitrary impedence boundary conditions are imposed. The field source is located on the plane, far from the two impedence discontinuities which occur at the edges of the strip. The high frequency, total field is represented as the sum of a geometrical optics field plus singly, doubly and triply diffracted fields.

The exact solution given by Maliuzhinets is asymptotically approximated for obtaining uniform expressions for the singly diffracted field. The asymptotic evaluation at this integral representation for the field, is performed via the modified Pauli-Clemmow method of the steepest descent. In applying this method, the pole singularities which may occur close to the saddle point due to the electric properties of the surface are taken also into account.

Higher order diffracted fields are calculated via a spectral, extended ray method. The integral representation for the singly diffracted field, impinging on the second surface impedence discontinuity, is interpreted as a superposition of inhomogeneus plane waves. Their diffraction can be calculated by analitically continuing into complex space the diffraction coefficient which has been derived by asymptotically approximating the Maliuzhinets solution. The integral representation for the doubly diffracted field obtained by superposition is then asymptotically evaluated, and approximate expressions for the field are derived which are uniform at all observation aspects and for any combination of impedence boundary conditions. In calculating the triply diffracted field, the same procedure is applyed by analitically continuing into complex space the double diffraction coefficient which has been obtained previously.

An efficient numerical procedure to calculate the special functions which occur in the Maliuzhinets solution is also presented. Calculations of the diffracted field in some example of practical interest are shown and discussed.

SESSION B-2 WAVEGUIDES I
TUESDAY 8:30 - 12:00
SANTA ANITA, Room C

Chairman: S. T. Peng
Polytechnic Institute of New York
Brooklyn, NY

AXISYMMETRIC TM MODES IN OPEN CYLINDRICAL WAVEGUIDES WITH CENTRAL CONDUCTOR

George C. Sherman and Claudette Hennessy
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We have conducted a parametric study of the time-harmonic, axisymmetric TM modes of an open cylindrical waveguide with a central conductor and circular crossection. The permittivities and conductivities of the inner and outer materials are arbitrary. The structure is specified in terms of cylindrical coordinates (r,ϕ,z) as follows. The structure is independent of ϕ and z. The central region $z<a$ is filled with a perfect conductor with infinite conductivity. The annular region $a<r<b$ is filled with medium 1 and the outer region $r>b$ is filled with medium 2. Medium j (with $j=1,2$) is homogeneous, having permittivity ε_j, conductivity σ_j and propagation constant k_j. The functional dependence of the fields on r is the same for all of these modes except that each mode has its own axial propagation constant h and radial propagation constant $\alpha_j=(k_j^2-h^2)^{\frac{1}{2}}$ in medium j.

The modes are well known for certain special cases of this structure. For $\sigma_2=\infty$, the structure is a coaxial transmission line having a TEM mode with no low-frequency cutoff and an infinite set of higher-order modes, all of which have cutoffs. For $\sigma_1=\sigma_2=0$ and $\varepsilon_1>\varepsilon_2$, the structure is a Goubau line having a "principal mode" with no cutoff and an infinite set of higher order modes (called secondary modes), all of which have cutoffs. For $\sigma_2=0$ and σ_1 very large, the modes are approximately the same as obtained by Sommerfeld for a circular wire of radius b and conductivity σ_2. The modes for the intermediate cases are not known, however, nor is it known how the modes for one of the above special cases are related to the modes of another special case.

We have filled in the intermediate cases for fixed frequency and radii a, b by solving numerically the modal equation for h with various values of $\varepsilon_1,\sigma_1,\varepsilon_2$, and σ_2. The results have shown two striking features.

a. Modes that exist for one set of parameters can "disappear" as the parameters vary in the sense that there is no longer a corresponding solution to the modal equation unless the branch of the square root specifying α_2 is changed. Similarly, new modes can "appear" in the same sense. We have found that by choosing the branch of the square root in a specific way, this disappearance and appearance of modes can be given a simple physical interpretation.

b. By appropriate variation of the parameters any mode can be made to pass continuously over into any other mode. For example, by passing from the coaxial transmission line to the Goubau line in different ways, it is possible to cause the TEM mode to pass continuously over to the principal mode or to any secondary mode.

ANALYSIS OF A TUNNEL WAVEGUIDE JUNCTION

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NTIA/ITS
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Underground coal mines are typically extensive labyrinths of parallel tunnels and right angle crosscuts. Consequently, tunnel junctions can have a significant effect on radio communications in mines. EM propagation in straight tunnels and around corners has been analyzed by lumping all the higher order waveguide modes into a single "diffuse" component (A. G. Emslie, R. L. Lagace, and P. F. Strong, IEEE Trans., AP-23, 192-205, 1975). Here we employ rigorous modal expansions for the fields, and the higher order waveguide modes are considered explicitly.

We adopt a two-dimensional geometry with a single tunnel junction of two infinitely long tunnels with impedance walls. Thus the attenuation of the waveguide modes due to the lossy rock walls is allowed for. A separate expansion in terms of rectangular cavity modes is utilized in the junction region. Mode matching is employed at the cavity-waveguide boundaries. The coefficients of the cavity modes are eliminated analytically, and the coefficients of the waveguide modes are obtained numerically through matrix inversion.

The incident field can be any one of the waveguide modes, and the resulting transmitted and reflected modes form a scattering matrix. Numerical results are presented for frequencies from 50 to 200 MHz. The numerical solution is found to converge smoothly, and numerical checks on power conservation, reciprocity, and the edge condition are well satisfied. A general result is that the lowest order mode is efficient in exciting the higher order modes in the crosscut tunnel, but is not efficient in exciting the lowest order mode.

MODE-CONVERSION EFFECTS IN RADIATION FROM PERIODICALLY-CORRUGATED DIELECTRIC STRUCTURES

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Brooklyn, New York 11201

Previous studies of radiation from periodically-corrugated dielectric structures were restricted to surface waves incident normally on grooved planar dielectric waveguides of infinite width. Under those conditions, no TE-TM coupling or mode conversion exists. The boundary value problem is a two-dimensional one, so that an incident wave of TE polarization, for example, will produce a radiated beam of only that polarization. We consider the general three-dimensional problem of surface waves incident obliquely on an infinitely-wide grooved planar dielectric waveguide, or incident normally on a dielectric structure of finite width. Now, coupling and mode conversion between TE and TM modes occur at every groove step in the grating, and a host of interesting physical effects are produced, including strong cross-polarization effects in certain narrow angular ranges, additional stop bands in the dispersion plots, and anisotropy, such that radiated beams sometimes appear in peculiar directions.

Mode-conversion effects for oblique guidance were analyzed by others recently, but only in the bound (non-radiating) region. Those theories, furthermore, employed perturbation approaches which are valid only for very shallow grooves, and could yield results only for bound stop bands but not for mode-coupling effects in the radiation region. An extension of the earlier rigorous theory for normal incidence to the oblique incidence case was developed recently by one of the authors, and we employ that analysis to obtain highly-accurate results for the many interesting physical effects referred to above.

QUASI-OPTICS OF THE COUPLING OF GUIDED MODES IN A CORRUGATED DIELECTRIC WAVEGUIDE

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

A nearly planar dielectric waveguide occupies the region $-d < x < d(z)$, and, $-\infty < y,\ z < \infty$. A periodic structure of shallow rectangular grooves is etched on the upper surface $x = d(z)$ of the dielectric waveguide. Since the periodic structure introduces a phase modulation, any two of the guided waves can be coupled selectively at the frequencies where the phase synchronism condition is satisfied. Only the two-dimensional problem in which the field quantities are independent of y is considered. The propagation directions of the guided waves are parallel to the grating vector. In the neighborhood of the frequency where the phase synchronism condition is satisfied, the slowly varying amplitudes of the two guided modes satisfy a pair of coupled-mode equations. These coupled-mode equations have been derived previously under various levels of approximation. All these derivations are based on the wave theory. In this paper, these coupled-mode equations are deduced using ray-theoretical techniques. Details will be presented for the contra-directional coupling between two TE modes and the results for the other types of coupling will be stated.

A plane wave-packet totally reflected from a periodically corrugated surface is first investigated. A major portion of the incident wave is specularly reflected and a small portion is coherently scattered in the backward direction when the phase synchronism condition is nearly satisfied. The wave-packets of the specularly reflected wave and the coherently scattered wave, in general, undergo lateral shifts at the interface. On the planar lower surface, there is only a specular reflection. The lateral shifts that occur on total reflection at the interfaces are included and the zig-zagging ray paths of the wave-packets propagating in the forward and the backward directions inside the nearly planar dielectric waveguide are constructed. Then, the existence conditions are derived for the zig-zagging wave-packets traveling in the two directions to form the guided modes in the dielectric waveguide. These existence conditions are the desired coupled-mode equations.

Some of the well-known results of the solution of the coupled-mode equations will be summarized.

MODE FILTERS FOR INTEGRATED OPTICS : APPLICATION OF ANISOTROPIC DIELECTRICS

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Indian Institute of Technology, Kanpur, U.P., India.

ABSTRACT

Electromagnetic wave propagation through a planar periodic structure consisting of alternate sections of isotropic and uniaxially anisotropic dielectric slabs shows the usefulness of dielectric anisotropy in mode-filtering action at optical and millimetric wavelengths. The structure is analysed using a coupled-mode perturbation theory, and the interaction lengths required for a complete filtering is found for the TM modes. The effects of variation in the spatial periodicity and other dimensions of the filter structure have also been investigated. The proposed structure has the advantage that it can be used at an intermediate position in the optical guide, and only the unwanted mode suffers loss in the ideal case. TE mode filters can also be designed along similar lines.

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SPECTRAL DOMAIN ANALYSIS OF DISCONTINUITY MICROSTRIP STRUCTURES

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and
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Department of Electrical Engineering,
Indian Institute of Technology, New Delhi, 110029, India

Discontinuities in microstrip transmission lines are invariably a part of microwave integrated circuits. There is considerable interest in their analysis. An accurate theoretical description, valid at low as well as at high frequencies, can be obtained with the hybrid-mode formulation of the spectral domain technique proposed by Itoh (IEEE Trans. MTT-22, 946-952, Nov. 1974). In this paper, we study the effect of those discontinuities which are amenable to solution when introduced in a rectangular microstrip resonator. They are: asymmetric and symmetric step-change in width, and a transverse slot.

The behaviour of the discontinuity in terms of its resonant frequency is adequately described by the form of the selected longitudinal current density. This has been verified from the data obtained by the experimental measurements.

These results indicate that the spectral domain technique predicts accurate results for two-dimensional problems as well as three dimensional problems (Itoh, NRS Meeting, Boulder, Colorado, 1978).

AN EXPERIMENTAL STUDY OF NONUNIFORM SURFACE REACTANCES SYNTHESIZED USING A GROUNDED PIN-BED STRUCTURE

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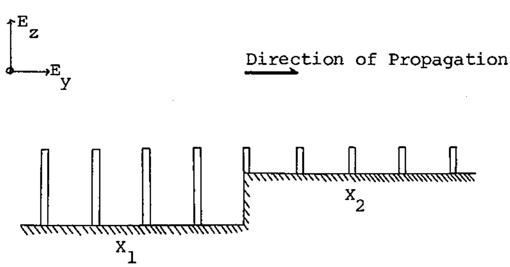
University of Wisconsin, Madison, Wisconsin 53706 USA
*On leave from School of Science, Griffith Univ., Nathan 4111, Austr.

King and Park (Electronics Lett. 1981, 17(1)) reported the theoretical aspects and preliminary experimental results for a lossless surface reactance structure consisting of a lattice of closely spaced thin conducting cylinders embedded in a dielectric with their axes normal to a conducting plane - a Fakir's bed. The desired dielectric tensor of the slab can be obtained by choosing the pin spacing, pin diameter, pin height and the dielectric constant of the embedding medium. Further verification of the theory has been made over a number of different pin configurations at 4.8 GHz ($\lambda_0 = 6.25$ cm) by measuring the vertical electric field strength E_Z versus height above the slab. (Only purely inductive surfaces capable of supporting a trapped surface were used).

Anisotropic slabs of this type have a reactance independent of the angle of incidence and can be constructed with two dimensional local variations in reactance. This is most easily accomplished by altering the pin height. Experimental results for this type of lateral variation in surface reactance will be presented.



SOME APPLICATIONS OF NON-UNIFORM WAVEGUIDES.

N. BERKANE, J.Ch. BOLOMEY

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This paper is devoted to non-uniform waveguide transitions used for connecting a monomode waveguide to multimode waveguides (e.g. parallel plate EMP simulators) or to radiating spaces (e.g. primary feeds, biomedical probes or applicators...).

A satisfactory behavior of the transition requires the production of a given field distribution in the output plane of the transition. For instance, a uniform distribution is needed as well for monomode excitation of TEM parallel simulators as for maximum gain horns. The profile control of the transitions has proved to be an interesting mean for obtaining some usefull field distributions. Indeed, a proper profile control provides the suitable higher order mode excitation over broad frequency bands.

A simple chain-matrix analysis constitutes an efficient way for numerically studying the non-uniform transitions. Many numerical results, in both the frequency and the time domain illustrate some interesting properties of parallel plate or rectangular waveguide transition with non linear profiles in the abovementionned applications.

Modes of an Array of Dielectric Waveguides

Leonard Eyges*

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An integral representation technique that was previously developed for calculating the modal properties of a single homogeneous weakly guiding dielectric waveguide of arbitrary cross sectional shape is extended to the calculation of the modes of an ensemble of two or more such guides, arrayed in arbitrary spatial configurations. Detailed numerical results are presented for two identical circular, square, and rectangular guides and excellent agreement with almost all published data is found. Similar calculations are made for two dissimilar guides. The technique is applied to a weakly coupled linear array of N identical, circular, uniformly spaced guides, where N=2, 3, 4, 5 or 6, and comparison is made with results that Meltz and Snitzer have obtained on the basis of coupled mode theory.

* This work was done jointly with Dr. Peter Wintersteiner

SESSION B-3 SCATTERING II
TUESDAY 1:30 - 5:00
SANTA ANITA, Room B

Chairman: R. E. Kleinman
University of Delaware
Newark, DE

A SIMPLE TECHNIQUE FOR SOLVING E-FIELD AND H-FIELD INTEGRAL EQUATIONS FOR CONDUCTING BODIES AT INTERNAL RESONANCES

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The E-field and H-field integral equations have been used extensively to analyze radiation and scattering from perfectly conducting bodies. However, at resonant frequencies of a cavity formed by a hollow conductor of the same shape as the original body, both the E-field and H-field integral equations fail. One way to get around the problem of inverting a singular E-field and H-field impedance matrix is to use a combined field formulation. For aperature problems a combined source formulation is more suitable.

However, in both the combined source and the combined field formulation there is some arbitrariness associated with the formation of the total impedance matrix. The total impedance matrix is a sum of the impedance matrix from the E-field integral equation plus an arbitrary constant times the impedance matrix from the H-field integral equation. The utilization of an arbitrary constant is an aesthetic drawback for these methods.

A method will be presented to obtain a solution at resonance from either the E-field or the H-field integral equation. The result obtained by this technique is unique and is the solution with the minimum norm. Moreover, a monotomic rate of convergence is guaranteed by this technique as the order of the approximation is increased. The method to be presented is an extension of Murray's method. The above described tecnique can also be utilized for solving singular matrix equations with the minimum norm.

ON IMPROVING THE STABILITY OF THE ELECTRIC FIELD INTEGRAL EQUATION AT LOW FREQUENCIES

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University, MS 38677

A number of researchers have reported instabilities in the moment method solution of the electric field integral equation at low frequencies. This paper traces these difficulties to the diminishing importance of the vector potential contribution to the electric field at low frequencies. As this term disappears with decreasing frequency, the electric field becomes more nearly conservative and the tested equations in the moment matrix system become dependent. In this paper, the authors present an alternative testing procedure which emphasizes the non-conservative contribution to the electric field and extends the low frequency range of the integral equation.

The method is applied to scattering by a rectangular plate. The instability of the low frequency solution is demonstrated, as is the stable behavior of the modified method. Interestingly, no additional computations are required in the modified method and it yields identical results with the conventional approach at high frequencies.

A HYBRID TECHNIQUE WHICH COMBINES THE MOMENT METHOD WITH AN ASYMPTOTIC CURRENT

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G. A. Thiele
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A hybrid method is presented which combines a moment method current with an asymptotic current on perfectly conducting bodies. Because the asymptotic current is asymptotic with frequency, the method works well on large bodies. Surprisingly, it works well on very small bodies too. The hybrid method of this paper does not need a priori knowledge of the asymptotic form of the current away from the moment method region as is the case in the hybrid GTD-MM technique.

The hybrid method of this paper employs the magnetic field integral equation (MFIE) and takes the asmyptotic current to be similar to the geometrical optics current. The current in the asymptotic region, which is dominated by the optics type current on the <u>entire</u> surface of the scatterer, is solved by an iterative method to give the approximate surface current. The difference between the approximate and true surface currents is calculated from the moment method current, which exists near shadow boundaries and/or sharp discontinuities in geometry. That is, the moment method current induces a current in the asymptotic region which is the difference between the optics type current and the true current.

Applications of this method to a wedge, square and circular cylinders in two dimensions are considered, and also the extension of the application to three dimensional problems is presented using a sphere as an example.

Results of the surface currents on those bodies for a plane wave incident are shown and compared with the GTD or the exact solutions.

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AN IMPROVED MODE-MATCHING METHOD FOR THE PROBLEM OF SCATTERING BY CONDUCTING CYLINDERS WITH ARBITRARY SHAPE

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In the determination of the field scattered by arbitrary conducting bodies, a number of numerical approaches have been heretofore developed. A typical one is the mode matching method based on the least-squares criterion, in which the fields are expanded into a set of basis functions of the Helmholtz equation and a least-squares boundary residual method is applied to the boundary conditions.

In a simple but basic example in which a plane electromagnetic wave of arbitrary polarization and incident angle is scattered by perfect conducting cylinders having arbitrary shape, it is usual to expand the fields into a set of nth order Hankel functions of the second kind $H_n^{(2)}(kr)$, $n=0,1,2,\cdots$.

There is, however, a serious difficulty in getting a satisfactory convergence of the series of these functions for the frequency range where the wavelength becomes comparable to or shorter than the characteristic dimension D of scatterer. This difficulty is, of course, the result of $H_n^{(2)}(kD) \approx H_{n\pm 4m}^{(2)}(kD)$, $m = 1,2,3,\ldots$ for $kD > 1$.

In this paper, we describe an alternative approach which is accurate and yet numerically efficient even for $kD \gg 1$ because it has no such the difficulty as mentioned previously.
In the present approach, a set of the Helmholtz equations is considered of which singularities are distributed on the positions given by the vectors $R_m(x_m,y_m)$, $m = 1,2,..,M$ inside the scatterer, and only the fundamental solution $H_0^{(2)}(k|R-R_m|)$ is employed to express the fields, where a vector R gives the observation points. Thus, putting R to the descrete positions $\overline{R}_n$, $n = 1,2,\ldots,N$ on the surface of the scatterer and applying the above-mentioned mode matching method, we can obtain the matrix equation for solving a set of the unknown expansion coefficients C_m accompanying with $H_0^{(2)}(k|\overline{R}_n-R_m|)$, and the radiation pattern as well as scattering cross section can be efficiently calculated.

If we appoint the distribution of singular points prior to the optimization procedures for the boundary residual, the problem becomes a linear optimization problem to solve the C_m's. This approach is employed first to solve a number of scattering problems, and it is shown that those results demonstrate our method to be numerically efficient. The positions of singularities have indeed a significant effect on the accuracy of solutions. Then the previous approach has to be extended to an improved one in which the positions R_m as well as the coefficients C_m should be solved in the optimization process. This approach leads the problem to a nonlinear optimization problem by least-squares which may be solved approximately by the asymptotic technique.

To illustrate the application of this improved method, numerical results are also presented with discussions of the convergence.

ON THE SCATTERING FROM AN

L-SHAPED WIRE

by

Clayborne D. Taylor
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An exact integral equation is derived for the current distribution induced on an L-shaped wire scatterer. Both axial and circumferential currents are obtained. By considering a smooth curvature at the bend no so-called "junction conditions" are needed. The results obtained by carrying out a moment method solution are compared with the conventional thin-wire scatterer preditions. Accordingly, the errors introduced by thin-wire approximations in treating bent-wire structures are quantified.

ELECTROMAGNETIC DIFFRACTION BY A NARROW SLIT IN AN IMPEDANCE SHEET--E-POLARIZATION

Donald F. Hanson
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The University of Mississippi
University, MS 38677

Composite materials have come into use lately in aircraft construction because of their high strength and low weight. For low frequency incident fields, the composite can be effectively modeled by an infinitely thin impedance sheet. The shielding effectiveness of a joint or seam between two composite panels needs to be evaluated as a function of slit width, panel thickness and panel conductivity. One possible formulation for obtaining the shielding effectiveness is described here.

The seam between composite sheets is modeled by a slit in an impedance sheet. Since only narrow slits are of practical interest, a quasi-static approach is developed using low-frequency impedance sheet boundary conditions (R. W. Latham and K. S. H. Lee, Can. J. Phys. 46, 1745-1752, 1968). Application of these boundary conditions yields a dual integral equation with sinusoidal kernel. The dual integral equation so obtained is then reduced to a single Fredholm integral equation of the second kind by assuming the solution can be written in a particular form (I. N. Sneddon, Mixed Boundary Value Problems in Potential Theory, Wiley, p. 113, 1966). This Fredholm equation is then solved numerically using Legendre polynomials. Closed form expressions are obtained for the perfectly conducting case.

COMPARISONS BETWEEN MEASUREMENTS AND COMPUTATIONS OF HF RADAR BACKSCATTER FROM CANONICAL SHIP-LIKE STRUCTURES

E. K. Walton and E. H. Newman
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ElectroScience Laboratory
Electrical Engineering Department
Columbus,Ohio

Measurements of the HF backscatter from scaled ship-like canonical targets on a ground plane were made using the Ohio State University ElectroScience Laboratory test radar range. The measurements yield the absolute radar cross-section magnitude and absolute phase (with respect to a chosen reference point) of the signal scattered from the target. Details of the operation and performance of the measurement system will be discussed. Variations in the location of various substructures (masts, long wire antennas, etc.) will be introduced and the impact on the backscattered signal will be shown.

The method of moments will be used to compute the backscattered signal for the same canonical shapes and their associated variations. The technique provides computed backscatter magnitudes and phases for shapes made up of connected plates and attached thin wires.

A discussion of the comparison between the results of the measurements and the computations will be given. Application of the results to HF radar backscatter from actual ships will also be discussed.

SCATTERING AREA OF A LARGE WIND TURBINE BLADE

D.L. Sengupta and J.E. Ferris
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Ann Arbor, Michigan 48109

The paper describes how the blade scattering area of a two megawatt wind turbine (WT), known as the MOD-1, at Boone, NC, has been determined from on-site measurements. Using the commercial VHF TV signals available in the area as the RF sources, measurements were carried out at test sites located about 1 km from the WT. With the receiving antenna beam directed at the WT, the received signals were recorded as the machine, having its two blades locked in the vertical position, was yawed in azimuth through 360°. The scattering effects of each blade were clearly identified in the received signals. From a knowledge of the maximum variation in the received signal caused by the blade scattering, the antenna characteristics in test environment, and the ambient field strengths measured at the test site and at the WT blade, the blade scattering area was determined by using an approximate theory developed. Results compare favorably with those obtained from laboratory scale model measurements.

EXPERIMENTAL DETERMINATION OF ELECTROMAGNETIC ENERGY ABSORPTION ON COMPLEX SHAPES; A PROGRESS REPORT

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USAF Academy, CO 80840

V. M. Martin, Instructor of Physics,
USAF Academy, CO 80840

R. W. BURTON, Professor of Electrical Engineering and Computer Science, University of Colorado,
Colorado Springs, CO 80907

This paper extends results previously presented to include quantitative efforts toward the comparison of known surface current amplitude distributions with those obtained through infrared techniques. It has been qualitatively demonstrated that the induced surface currents resulting from incident electromagnetic radiation produce I^2R heating detectable through thermographic techniques. Intense areas of detected I^2R heating can be identified in relation to the entire object, thus allowing for the determination of relative surface current amplitudes.

For simple shapes, surface currents have been measured and numerical solutions developed. The results using the thermographic techniques are compared to these known results. Considerations given to the directionality of emitted radiation for a particular geometry are discussed. A coating approach to enhancing the infrared results is also presented. From the results on simple shapes, the techniques can be applied to more complex shapes where surface current distributions are more difficult to model.

The use of this method of detection and scaled down modeling of complex shapes provides an accurate and rapid method of examining an entire object with respect to the anticipated electromagnetic energy absoption. The determination of the amplitudes of the induced surface currents gives an excellent first order approximation of the exact characterization of the induced surface currents. The technique developed allows for exceptional cost effective simulation of potential design alterations of the geometric factors involved in the location and possible redistribution of absorbed electromagnetic energy.

SESSION B-4 WAVEGUIDES II; OPTICAL AND MILLIMETER WAVEGUIDES
TUESDAY 1:30 - 5:00
SANTA ANITA, Room C

Chairman: E. F. Kuester
University of Colorado
Boulder, CO

PROPAGATION CONSTANTS FOR STEP-INDEX OPTICAL FIBERS OF ARBITRARY CROSS-SECTION AT HIGH FREQUENCY: Edward F. Kuester and Rozalina Ebrahimian, Electromagnetics Laboratory, Dept. of Electrical Engineering, University of Colorado, Boulder, CO 80309

A variety of numerical methods exists for computing propagation constants for modes of optical fibers of arbitrary cross section. Certain special core shapes (e.g., rectangular) also permit approximate analytical evaluation of the mode properties. In the present work, we make use of the polarization integral equation for an arbitrary step-index fiber, and the fact that the transverse field dependence of its modes should be close to that of the corresponding Dirichlet problem (TM modes of the corresponding hollow metallic guide) for sufficiently high frequencies. Asymptotic evaluation of a variational expression provides explicit formulas for the propagation constants in this limit, which are compared to ones known for circular and rectangular cores.

ON THE ANALYSIS OF INHOMOGENITIES IN OPTICAL WAVEGUIDES

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Dielectric waveguides of circular cross section are extremely useful for long distance communications at millimeter wave frequencies and beyond. These waveguides typically consist of a core dielectric material of refractive index n_1, surrounded by a cladding of refractive index n_2 ($n_2 < n_1$) and are usually several kilometers in length. Inhomogenities of some kind or other invariably occur in the manufacturing process of such fibers and these imperfections cause the modes of the optical waveguide to couple among one another as well as couple to the radiation modes. Power transferred to other guided modes results in signal distortion while the power transfer to the radiation modes results in waveguide losses which in turn determine the minimum attenuation obtainable from such a waveguide. In the present study, we consider the propagation of the dominant HE_{11} mode in the fiber and try to estimate the losses that occur due to various forms of irregularities: (a) a small reduction in diameter, (b) a break in the cladding, (c) a smooth taper, (d) a small shift in the guide axis, and (e) a smooth bend. The calculations are based on the method of transverse cross section and are well-described in some text books (L. A. Vaynshteyn, Open Resonators and Open Waveguides, Ch. 10, 1969; V. V. Shevchenko, Continuous Transitions in Open Waveguides, Ch. 3, 1971). In each transverse plane of the irregular waveguide, the appropriate expansions are written using the system of characteristic modes of the discrete and continuous spectra, and using the orthogonality relations, expression are derived for the coupling coefficients (D. Marcuse, Theory of Dielectric Optical Waveguides, Ch. 3, 1974). The radiated field due to the various inhomogenities is determined using the method of stationary phase. Numerical results will be presented.

OPTICAL COMMUNICATIONS WITH ELLIPTICAL FIBERS

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Department of Electrical and Computer Engineering
California State University, Northridge
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The realization of extremely low loss fibers has radically changed the outlook for optical communications. Single mode fibers with loss as low as 0.2 dB/km at 1.6 μm and a bandwidth-length product as high as 100 GHz·km have been fabricated. Improvements in physical strength in the fibers enabled the design of fiber optical system (Wong, et. al., Optical Engineering, 2, 1981) capable of withstanding severe operating environments.

The characteristics of waveguide with elliptical cross-section have been studied (Rengarajan, et. al., IEEE Transactions on Microwave Theory and Techniques, 10, 1085-1095, 1980). It was determined that a single mode fiber with elliptical cross-section is capable of tramsmitting information in two modes with different polarization. The ability to maintain polarization for propagating mode in the fiber is important for applications which depend upon the interactions of polarized light. This paper describes the results of a study on two-way optical communication with a single mode elliptical fiber. Operations are performed to polarize the beams orthogonal to each other from two communicating stations. This allows the beams to be separated readily by integrated optical waveguide devices. The effects of stress-induced birefringence as well as the need of carrier up-conversion are also analyzed.

INVESTIGATING THE PROPERTIES OF THE RADIALLY INHOMOGENEOUS OPTICAL FIBERS USING THE PREDICTOR-CORRECTOR METHOD

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Although many analytical studies have been carried out on the radially inhomogeneous fibers,earlier efforts have neglected the effects of a finite cladding to accommodate some approximations. Recently,modified W.K.B. methods have been proposed to take boundary effects,including an infinite homogeneous cladding,into considerations. They seem to be directed towards some special profiles e.g. parabolic or α-power,and,in some cases,a numerical implementation of the analytical results is still lacking. Therefore,accurate and efficient numerical methods are still very important in the study of optical fibers with arbitrary refractive index profiles.

In this paper,we will present the predictor-corrector method,which is accurate and highly efficient compared with the Runge-Kutta(Dil and Blok,1973;Yip and Ahmew,1974) and collocation methods(Nguyen and Yip,1980). Its accuracy was first tested with the problem of an inhomogeneous slab with a finite cladding(Yip and Colombini,1978),and then with that of a radially inhomogeneous fiber having a parabolic core and a finite homogeneous cladding(Yip and Ahmew,1974). The P-C method is then used in studying the effects on the propagation characteristics produced by a central 'dip' and a 'valley' between the core and cladding in the index profile of a radially inhomogeneous fiber,normally having a parabolic core and a finite cladding. We will present and discuss numerical results of the dispersion curves of the first seven modes,their field and power distributions as well as their phase and group velocities. Their departures from those of the regular fiber with a parabolic index core will be emphasized.

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A NUMERICAL SOLUTION FOR INHOMOGENEOUS DIELECTRIC WAVEGUIDES.

Ch. PICHOT

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Using a vectorial integral equation for the electric field inside the waveguide, a numerical method is developed in order to compute the propagation constants and the field configuration in inhomogeneous bidimensionnal waveguides of arbitrary shape. Such guides have practical interest in optic or millimeter-wave integrated circuits. This method generalizes a former one aimed to treat the inhomogeneous slab problem (Ch. Pichot, Opt. Comm., 23, n° 2, 285-288, 1977).

In order to test the accuracy, various and typical waveguides have been studied and the results compared with those obtained by other numerical techniques (C. Yeh et al, Appl. Opt., 18, n° 10, 1490-1504, 1979) and with approximate solutions in particular cases (E.A.J. Marcatili, Bell Syst. Tech. J., 48, 2071-2102, 1969, for example).

By means of performant algorithms, the computation time is very low for waveguides supporting the dominant modes E^x_{11} and E^y_{11}. But for multimode waveguides, the method will need a large computing time as the number of modes is increasing. Nevertheless, several approximations can be made which provide good results with less computing time and memory storage.

SCATTERING OF SURFACE-WAVES BY A DIELECTRIC STEP DISCONTINUITY

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When a surface-wave mode impinges upon a step discontinuity on a dielectric planer waveguide, reflection and transmission as well as scattering of the surface-waves may occur.
Such a discontinuity may be due to the difference in the geometric or material properties of the guides or both.

We consider here the three-dimensional vector boundary value problem in which a surface-wave is incident *obliquely* at an angle θ to the two-dimensional discontinuity plane. In this case, the boundary value problem supports only hybrid modes,i.e., it requires the necessary coupling between TE and TM modes which are able to exist independently in an infinite slab waveguide.

Moreover, such electromagnetic fields consist of both a finite number of discrete surface-wave modes and a continuous spectrum of radiation modes. In the analysis, the infinite interval (o , ∞) of a continuous spectrum is approximated by the finite one (o , w), so the approximated fields no more fulfill rigorously the boundary condition at the discontinuity, but are continuous always with some errors which have a significant effect on the convergence of solutions.
Then the present paper solves the problem by imposing the condition which minimizes the errors in the continuity condition in the sense of least-squares. Such an approach leads a coupled system of integral equations for a reflection matrix R, a transmission matrix T and a functional form of a continuous spectrum.

Numerical results are shown to illustrate the important effect,i.e., the angular dependence of coupling between TE and TM modes. We apply these results in order to derive the rigorous dispersion characteristics of dielectric strip waveguides which often show the interesting leakage effect predicted by Oliner.
The other potential applications of this technique will be shown.

Suspended and Inverted Microstrips for Millimeter-Wave Applications

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Suspended and inverted microstrip lines have been widely used for millimeter wave circuits. However, surprisingly little information on their dynamic characteristics is available. Furthermore, a patch antenna made of suspended or inverted microstrips is expected to be a good candidate for inexpensive planar radiating structures. These can perform better than conventional patch antennas because the location of the radiating patch is relatively far away from the ground plane.

In this paper, we make use of the spectral domain immittance matrix approach for analyzing two and three dimensional structures. With this approach, the spectral domain Green's function is readily derived as a superposition of driving point impedances. The formulation is done for the strip interface after equivalent transmission lines are introduced in the transverse direction for each spectral component. Since the process is essentially to find the driving point impedances, the formulation is straightforward and may be done almost by inspection. In fact, the method can handle structures with more than three layers of dielectrics by simply cascading the transmission lines corresponding to each layer. The form of the Green's function for the transmission line is identical for the antenna problem and can be readily modified for either case.

Once those functions are available, we obtain a homogeneous matrix equation for either two or three dimensional problems by using Galerkin's method. In the two dimensional case, we solve an equation for the propagation constant and subsequently calculate the characteristic impedance. For the antenna problem, the patch is viewed as an open resonator and we seek the complex resonant frequencies. The real and imaginary parts give the resonance and radiation losses, respectively. A number of numerical results will be presented for both the transmission line and antenna.

NEW POLARIZATION PRESERVING SINGLE-MODE FIBERS

THE LAYERED FIBERS

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In several important applications, polarization of the propagating field in a single-mode fiber needs be preserved. Stress-induced birefringent fiber or deformed core fiber may satisfy the needed requirement. However, to achieve targeted isolation for the two orthogonal dominant modes, the required stress is excessively high for stress-induced birefringent fiber and the loss is excessive for deformed-core fiber. A new solution is proposed. Using the concept of artificial dielectrics consisting of horizontally or vertically layered uniform dielectrics, we may produce sufficient birefringent effect in a single-mode fiber to enable proper isolation for the two orthogonal dominant modes. We have carried out an analysis of multi-layered dielectric guiding structure for the two orthogonal dominant modes. Results show that we can readily achieve the targeted isolation for the two orthogonal dominant modes. The beat length of these modes, which measures the degree of isolation, could be as small as 2 mm for $\lambda = 1$ μm.

SESSION B-5 GOUBAU MEMORIAL SESSION
WEDNESDAY 1:30 - 5:00
SANTA ANITA, Room C

Organizer: David C. Chang
University of Colorado
Department of Electrical Engineering
Boulder, CO

SESSION
CHAIRMAN: James W. Mink
U.S. Army Research Office
Research Triangle Park, NC

EULOGY: Felix Schwering
U.S. Army CORADCOM
Fort Monmouth, NJ

Leo Felsen, Chairman International Commission B on Fields and Waves
Polytechnic Institute of New York
Farmingdale, NY

THEORY OF BEAM WAVEGUIDES: A REVIEW

F. Schwering
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Among Dr. Goubau's numerous contributions in the area of EM theory and techniques, two are of particular importance: The invention of the surface wave transmission line (Goubau-line) and the development ofthe beam waveguide. The subject of this presentation is a review of the theory of the beam waveguide.

Beam waveguides can be described as consisting of a sequence of equally spaced "phase transformers" which periodically re-set the cross sectional phase distribution of a transmitted wavebeam; the phase transformers may take the form of lenses or (curved) reflectors. The theory shows that any transmitted beam can be written as a superposition of characteristic functions whose field distribution is iterated with the spacing of the phase transformers. Similar to the modes in a metal waveguide, these characteristic fields form a complete orthogonal system and have therefore been termed beammodes. The cross sectional field distribution of the beammodes is determined by Gauss-Laguerre functions in the case of circular symmetry and by Gauss-Hermite functions in the case of rectangular symmetry. Diffraction losses (spill-over losses) of the beammodes can be made extremely small, even for lenses or reflectors of moderate size.

Although beam waveguides were first investigated at mm-wavelengths, their theory applies, of course, at any frequency and specifically in the optical frequency band for which the beam waveguide is particularily attractive as a transmission medium of extremely low loss, high channel capacity, and minimum dispersion.

SOME ASPECTS OF GEORG GOUBAU'S EXPERIMENTAL INVESTIGATIONS AT FORT MONMOUTH

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Fort Monmouth, NJ 07703

J. W. Mink
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Research Triangle Park, NC 27709

Those of us who had the privilege of working in close association with Dr. Georg Goubau are aware of his many unique talents and the wide range of his scientific interests. He was equally at home performing or directing an experiment in the laboratory as he was in conducting a highly abstract theoretical investigation. In this paper we will discuss some of his experimental studies which have led to major scientific and practical contributions. His earliest work for the U.S. Army was concerned with the surface wave transmission line (often called Goubau or G-line). We will discuss his early G-line experiments and typical applications. The subject of the second study was the Beam Waveguide, including experimental verification of the beam mode concept. The beam waveguide, consisting of a sequence of low loss lenses or reflectors which guide coherent EM radiation for long distances, was first investigated at millimeter wavelengths. These investigations were followed by a 1 km model guide operating at optical frequencies. Several increasingly refined versions of this guide were studied, culminating in a beam waveguide utilizing a fully automated lens alignment procedure. Finally, we will discuss contractual work managed by Dr. Goubau at the University of Wisconsin. This work includes studies on the surface wave phenomenon, on microwave branching filters, and on wave-beam resonators.

MATHEMATICAL MODELLING OF MULTI-ELEMENT

MONOPOLE ANTENNAS

by

G. Goubau (Deceased)

N. N. Puri

F. Schwering

Abstract

This research document presents a new theory for the analysis of multi-element antennas which consist of interconnected conductive structure elements of electrically small dimensions. The theory is based on the retarded electromagnet potentials which permit a diakoptic approach to the problem. The antenna is broken up into its individual structure elements. Each element is assumed to be excited, a) by currents which are impressed at its terminals, i.e. junctions with adjacent elements (current coupling), and b) by the electric fields of the currents and charges on all the other elements (field coupling). Both excitations are treated independently. Each impressed current produces a "dominant" current distribution, a characteristic of the element, which can be readily computed. Current coupling is formulated by "intrinsic" impedance matrices which relate the scalar potentials at the terminals of an element, caused by its dominant current distributions, to the impressed currents of the element. Field coupling produces "scatter" currents on all the elements, and is formulated by a "field coupling" matrix which relates the scalar potentials at the terminals, caused by field coupling, to the impressed currents at all the terminals. Intrinsic and "field coupling" are combined to form the "complete" impedance matrix of the diakopted antenna. Enforcing continuity of the currents and equality of the scalar potentials at all the interconnections between the elements yields a system of linear equations for the junction currents and the input impedance of the antenna. Current coupling dominates over field coupling. Field coupling due to the dominant current distributions of the elements is of primary importance while field coupling due to the scatter currents is, in general, negligible. This theory is applied to several multielement antennas and the results are compared with other methods to highlight the numerical advantages.

GUIDING MECHANISMS ON OPEN, PLANAR STRUCTURES

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and

Tatsuo Itoh
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The role of the critical angle in determining the propagation characteristics of a two-dimensional surface-wave structure such as a dielectric slab or a Goubou line, is examined from a physical viewpoint. In addition to producing an evanescent wave external to the dielectric region, it is shown that a transverse resonance can be established so long as the Goos-Hänchen shift resulting from a plane wave reflected beyond the critical angle is properly taken into account. The same phenomenon is used to explain the propagation of a guided mode along a wide microstrip. This can be accomplished by first considering the excitation problem of a grounded dielectric slab with a semi-infinite microstrip patch. A total reflection of a TEM wave under the patch can occur whenever the longitudinal wave number of such a wave is greater than that of the propagating surface-wave mode(s) supported by the dielectric slab in the absence of a microstrip patch. The evanescent field distribution outside the microstrip of course is much more complicated than the two-dimensional guiding structures.

Following a discussion on how this concept can also be applied to planar dielectric waveguides in general, comparison will be made based upon numerical results computed for these structures.

RADIATION CHARACTERISTICS OF LEAKY DIELECTRIC WAVEGUIDES

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University of Illinois
Urbana, Illinois

In this paper, we report the results of theoretical and experimental investigations of a class of open dielectric structures which are periodically perturbed to induce leaky-wave radiation. These leaky-wave antennas are especially suited for millimeter and quasi-optical wavelengths where they can be made compatible with planar dielectric waveguides. A combination of the spectral domain approach and the effective dielectric constant method is employed to derive the complex propagation constant for the leaky-wave structure. The theoretical results are confirmed by experimental measurements carried out at millimeter wavelengths. Experimental studies also show that a good antenna design requires the tapering of the leaky-wave structure which serves two purposes. First, it provides a good match from the waveguide to the antenna in the launching region and thus suppresses untoward radiation at the junction. Second, the taper helps to achieve uniform radiation throughout the length of the antenna as it provides monotonically increasing leakage along the antenna to compensate for the energy loss due to radiation.

The paper also describes a combination of channel guide horn and dielectric leaky-wave antenna design which has the desirable characteristic that it confines its radiation in the upper hemisphere only.

Extensive parameter studies for both of the antenna designs have been carried out and are reported in the paper. It is shown that the antennas must be designed very carefully in order to enhance the leaky-wave radiation in the desired direction and suppress the unwanted radiation at other angles.

BENDING LOSSES OF OPEN WAVEGUIDES

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The nature of modes on open waveguides (and of surface waves in particular) is such that irregularities along their axes cause not merely conversion into cutoff (and hence, energy-storing only) higher modes, but also into fields which are radiated away from the structure and show up as power lost. The past ten years, under the impetus of theoretical research on optical waveguides, have seen a detailed study of the effects of curvature on the guiding properties of surface waveguides.

This paper will review the present understanding of this problem, its physical background, and the basic analytical expressions for curvature loss. The continuous radiation loss (due to the curvature R^{-1} itself rather than changes in curvature) has the effect of introducing an attenuation constant of the form $\alpha = c_1 R^{-p} \exp(-c_2 R)$ where c_1 and c_2 are constants. The power law is $p = 0$ for slab (two dimensional) guides, $p = \frac{1}{2}$ for fibers with a homogeneous cladding, and $p = \frac{3}{2}$ for channel guides embedded in a relatively dense semi-infinite substrate.

Radiation from abrupt changes in curvature is of a more localized nature, and is proportional to $(R_1^{-1} - R_2^{-1})$, where R_1 and R_2 are the radii of curvature on either side of the jump. Such problems are all of a well-defined surface-wave nature; the fields exhibit an exponential decay away from the guiding structure. These results are applicable to the Goubau line so long as the frequency is high enough that the mode is a surface wave; at lower frequencies, the fields begin to be quasi-TEM in nature, and associated with a more algebraic decay with distance. Extension of bending loss theories to general types of TEM or quasi-TEM structures (including Goubau lines) encounters a number of problems related to a distinctly different physical picture of the loss process. These will be explored at the end of the paper for a few of the simplest of such structures.

NEW PHYSICAL EFFECTS DUE TO MODE COUPLING IN VARIOUS DIELECTRIC STRUCTURES

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Three physical structures are selected to illustrate the new phenomena: a dielectric step junction, a dielectric strip waveguide, and a planar periodically-grooved dielectric waveguide. When a surface wave strikes the step junction at normal incidence or is guided by the planar periodic waveguide in a direction perpendicular to the grooves, the resulting two-dimensional boundary-value problems have been analyzed for TE and TM modes independently in the literature by us and by others. When the incidence on the dielectric step junction occurs at an arbitrary angle, or when the guidance by the planar periodic dielectric waveguide is at an arbitrary angle to the grooves, the boundary-value problems become three-dimensional ones in which the TE and TM waves are no longer independent but are coupled together, giving rise to interesting new physical effects. The dielectric strip waveguide automatically involves the equivalent of oblique incidence on the dielectric step corresponding to the side of the strip.

The new physical effects resulting from the mode coupling include the following. For the dielectric step junction, an incident wave gives rise to reflected and transmitted waves of the opposite polarization; in addition, for TE surface waves the junction exhibits a Brewster angle. On the dielectric strip waveguide, leaky modes arise instead of previously-expected purely-bound modes, and resonance effects appear in the leakage process. Furthermore, these leaky modes constitute a new class, since the leaking energy possesses a polarization opposite to that present in the main body of the waveguide, in contrast to customary leaky modes. Oblique guidance by the periodic dielectric surface produces four stop bands instead of the usual two in the Bragg reflection region, strong cross-polarization effects in portions of the radiation region, and interesting anisotropy phenomena.

SESSION B-6 RADAR WAVEFORMS AND IDENTIFICATION
THURSDAY 8:30 - 12:00
SANTA ANITA, Room C

Chairman: A. Ksienski
Ohio State University
Columbus, OH

RADAR SPECTROSCOPY: T-MATRIX APPROACH

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H. Überall
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The electromagnetic resonance spectrum of radar targets constitutes a code which can be used for target identification purposes. The resonance frequencies and widths may be represented by poles in the complex frequency plane, which can be located via the observed frequencies and decay constants of transient echoes as demonstrated in the Singularity Expansion Method (SEM). In a previous study (G. C. Gaunaurd, P. J. Moser, and H. Überall, J. Appl. Phys. Vol. 52, No. 1, 1981) we have illustrated the use of radar resonances for a determination of the material composition of penetrable radar targets of known (layered spherical) shape. In the present paper, we indicate how the resonances spectrum may be used for shape discrimination purposes by evaluating the splitting of the complex frequency poles of a conducting sphere into pole doublets as the sphere is deformed into a prolate spheroid. Our results were obtained by employing the T-matrix approach (P.C. Watermann, Proc. IEEE 53, 805-812, 1965).

R- MATRIX THEORY OF RADAR SCATTERING

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J. D. Murphy, A. Nagl, and H. Überall
Physics Department, Catholic University, Washington, DC 20064

Radar scattering amplitudes from finite bodies contain poles in the complex frequency plane, which give rise to scattering resonances that are most pronounced in the case of penetrable scatterers. For the example of a conducting sphere coated with a homogeneous dielectric, we have studied the analytic properties of the scattering function, exhibiting its meromorphic character via Wigner's R matrix formalism as developed in the context of nuclear scattering theory. From a more physical viewpoint, the individual normal-mode scattering amplitudes are shown to be separable into the resonant Mittag-Leffler series, interfering with a non-resonant background which corresponds to specular reflection. The resonances fall into distinct families, which are seen to constitute the manifestations of creeping waves that generate the resonances via phase matching after repeated circumnavigations, and whose dispersion curves are obtained here.

SYNTHESIS OF RADAR SIGNAL FOR EXCITING A SINGLE-MODE BACKSCATTER FROM A SPHERE

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For the purpose of identifying and discriminating a radar target, it is desirable to have capacity to selectively excite natural resonance modes of the target. To do so, it is necessary to synthesize the incident radar signal in such a way that when it illuminates the target, the backscatter contains only a single natural mode of the target. A single-mode backscatter leads to an easy identification on the scope, a better signal-to-noise ratio, and an easier process with narrow-band filters and amplifiers.

The geometry of a conducting sphere is considered. First, the backscatter induced by an arbitrary incident signal is obtained in Laplace transform. The set of natural frequencies and their distribution on the S-plane are identified. The impulse response of the sphere is determined next. An approximate method is developed to determine the impulse response which shows the creeping wave contribution. This method consists of summing up an infinite number of natural modes of the sphere. It is also found that even though an infinite number of natural modes is required to produce an accurate impulse response in the early-time period, it is only necessary to consider a finite number of relevant natural modes to generate an accurate impulse response in the late-time period.

It is possible to synthesize a required waveform for the incident signal to excite a single-mode backscatter in the late-time period. Required waveforms for the incident signal to excite various single-mode backscatters are given. When the required incident signal for exciting a particular natural mode of a known sphere is applied to a wrong sphere, the waveform of the backscatter is different from that of the expected natural mode. This phenomenon provides a mechanism for discriminating the wrong target.

AN APPROACH TO RADAR TARGET IDENTIFICATION

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Radar targets can usually be characterized by a small number (one to five) of scattering centers which are reasonably stationary for a small range (5° to 10°) of aspect angles. Radar signals back-scattered from the various centers will interfere, and the total signal will contain information about the spatial distribution of the scattering centers. If the interrogating signal is a short pulse, the locations of the scattering centers can be obtained directly, but many surveillance radars do not possess sufficient bandwidth to accomplish this. The proposed method of target discrimination enables the spatial frequencies (an equivalent representation of the locations of scattering centers) to be extracted from RCS data gathered within a bandwidth of 30% or less. These spatial frequencies can then be correlated with those of known scatterers to achieve target identification.

The total back-scattered signal can be expressed as the sum of N complex exponentials, where the exponential quantity is the product of the wave number k and a spatial frequency, and where N is the number of scattering centers. The amplitudes and spatial frequencies total 2N unknowns, which can be simultaneously solved for if the value of the total signal is known for at least 2N different values of k. The solution to this nonlinear problem was first obtained by Prony in 1795, and computer programs based on his algorithm have been used successfully for the extraction of SEM poles in EMP analysis [M. L. Van Blaricum and R. Mittra, IEEE Trans., AP-26, 175-182, 1978].

This numerical technique has been adapted for use here for the problem of target discrimination. Prony's method involves the inversion of two N x N matrices and a search for the roots of an N^{th} order polynomial.

Several test cases, e.g., rectangular cylinders, thin strips, and thin plates, are being investigated and the results of the study will be given in the paper. The bandwidth requirements for reliable recovery of the scattering centers are being studied both in the absence and presence of simulated noise, and the results of the numerical experiments will be presented.

MODELLING OF NONLINEAR SCATTERERS WITH NONLINEAR RADAR CROSS SECTIONS

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A number of man-made objects, detected by radar, exhibit nonlinear effects which in turn result in new frequency components appearing in the backscattered field. Consequently, it is desirable to develop a quantitative and systematic method to analyze scattering data from such nonlinear objects. By utilizing nonlinear transfer function concepts, one can model the nonlinear scattering effect in terms of a hierarchy of nonlinear radar cross sections. We have developed a method to digitally compute nonlinear transfer functions directly from the raw input and output time series data. Specifically the nonlinear transfer functions are computed in terms of higher order cross spectra (bispectra and trispectra). (J.Y. Hong, Y.C. Kim and E.J. Powers, Proc. IEEE 68, 1026-1027, Aug. 1980). In this paper we will show how these concepts may be extended to model scattering from nonlinear objects in terms of a hierarchy of nonlinear scattering cross sections. These cross sections provide additional signature information which may be useful in classifying and identifying targets. The approach requires the input to exhibit stationary Gaussian statistics. To meet this requirement, we consider two possible inputs: sum of sinusoids, and an ensemble of sinusoids with Rayleigh distributed amplitudes and uniformly distributed phases. In this paper, we will discuss the ideas underlying the approach and various practical aspects associated with the digital implementation.

HYPOTHESIS TESTING APPLIED TO RADIO DIRECTION FINDING

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Statistical hypothesis testing is applied to the problem of determining the probability-of-detection, P_D, of a signal emitted from one of M possible emitters whose geometric coordinates are known apriori. Using an interferometer angle-of-arrival technique the probability density function (pdf) for the angle of emission is assumed to be Gaussian with a mean equal to the exact angle of radiation and a standard deviation, σ, dependent on (signal-to-noise)$^{-1/2}$. Picking a linear arrangement of equally spaced potential emitters, an expression for the risk function is formulated so as to allow for the determination of the M-1 boundaries defining the M decision regions. This allows for an exact determination of P_D. Limitations of this exact formulation are discussed, where it is noted that extension of the theory to the general case of a large number of M equally likely locations may be beset by very complicated computations.

To handle such cases a lower-bound is derivable by characterizing the signal set as consisting of elements which are uncorrelated and orthogonal. When this is done the issue to be resolved is cast in the form of the well-understood problem of the detection of "M-ary" Signals by matched filters. Probability of detection curves are available and are exploited to arrive at the lower bound on the probability of detection cited. In this regard it is shown with mathematical rigor that E_b/N_0 (energy/bit-to-noise power density) is equivalent to $1/4\ (\Delta\theta/\sigma)^2$ where $\Delta\theta$ is the angular separation between sites as seen by the interferometer. Using appropriate propagation models the P_D vs. range curves are generated. Extension of the reported work to the multiple hypothesis (signals) case is possible. Here an example of a typical hypothesis involves the simultaneous reception of n signals associated with the true directions of n sources. Because the simple hypothesis where n is 1 (one) is characterized by Gaussian pdf's the multiple hypothesis pdf is therefore multidimensional Gaussian and mathematical tractability is present.

AN AUTOMATED MICROWAVE MEASUREMENT FACILITY FOR THREE-DIMENSIONAL TOMOGRAPHIC IMAGING BY WAVELENGTH DIVERSITY

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Abstract

Following a brief review of the principles of wavelength diversity 3-D tomographic imaging we will describe a novel broad-band (2-18) GHz automated microwave holographic imaging facility recently incorporated in an anechoic chamber environment. The facility is suitable for 3-D wavelength diversity imaging of perfectly conducting objects. It allows gaining access to the 3-D Fourier space of a 3-D scattering object rapidly and accurately via measurement of the multi-aspect frequency response of the object and data correction. Hybrid (opto-digital) data processing of collected data used in image reconstruction is discussed and several examples of images reconstructed from both computed and experimentally measured data are given. Finally the implications of the result in inverse scattering and development of a new generation of 3-D tomographic imaging radars are discussed.

SESSION B-7 INVERSE SCATTERING
THURSDAY 8:30 - 12:00
SANTA ANITA, Room B

Chairman: P.L.E. Uslenghi
University of Illinois,
Chicago Circle

AN INVERSE SCATTERING METHOD FOR ONE-DIMENSIONAL PROBLEMS IN ABSORBING MEDIA

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The problem of determining the profile of refractive index of one-dimensional inhomogeneous and absorbing dielectric media from the analytic representation of the scattering matrix is examined. A method, which is based on an extension of Gelfand-Levitan theory (M. Jaulent, J. Math. Phys., vol. 17, p. 1351-1360; 1976), is applied to two examples:

1. An exactly solvable example, where the scattering matrix, S(k), is a rational function of wave number k. If sufficiently restrictive conditions are imposed, then the real and imaginary parts of the refractive-index profile can be determined uniquely. This case will be demonstrated by a reflection coefficient similar to the two-pole Butterworth approximation, which was previously considered for the non-absorbing case.

2. A strongly reflecting example, where the scattering coefficient S(k) is close to unity. Here the system of coupled Gelfand-Levitan equations can be solved iteratively. The first-order solutions will be compared to the Born approximations for lossy dielectric media.

The applications of this method to stratified dielectric media and nonuniform transmission lines will be discussed.

DIRECT AND INVERSE SCATTERING OF COMBINED FIELDS

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Combined phasor fields of the type $\underline{E}_{\pm} = \underline{E} \pm jZ\underline{H}$ have been previously considered by Rumsey, Baum and others; here they are utilized in studying the relationship between near field and far field. If the radiated or scattered far field is written as

$$\underline{E}^{s}_{\pm}(\underline{r}) \sim \frac{e^{-jkr}}{kr}\underline{S}_{\pm}(\hat{r}), \quad (r \to \infty), \qquad (1)$$

then use of the Stratton - Chu formula yields:

$$\underline{S}_{\pm}(\hat{r}) = (\mp 1 - j\hat{r}\times)\, \underline{I}_{\pm}(\hat{r}), \qquad (2a)$$

$$\underline{I}_{\pm}(\hat{r}) = \frac{1}{4\pi}\oiint_{S} \underline{K}_{\pm}(\xi) e^{j\hat{r}\cdot\underline{\xi}}\, ds, \qquad (2b)$$

where $\underline{K}_{\pm} = \hat{n}_1 \times \underline{E}_{\pm}$ is the combined surface current density on any closed surface S surrounding the radiating or scattering object, $\hat{n}_1$ is the outward unit normal at $\underline{r}_1$ on S, and $ds = k^2 dS$ and $\underline{\xi} = k\underline{r}$, are dimensionless.

Formula (2) establishes a Fourier-transform relationship between near field and far field, that is utilized in deriving several useful properties of direct and inverse scattering. In particular, an inverse scattering formula is obtained that includes Bojarski's physical-optics formula as a special case.

AN ALGORITHM FOR PROFILE INVERSION

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An electromagnetic plane wave propagating in a stratified lossy medium sets up reflected fields at the interfaces of each stratified layer. These reflected fields are caused by the impedance mismatch between layers as well as the internal reflections within each layer due to the lossy medium. In general, it can be shown that the total reflected field $b_{k-1}(t_j)$ in (k-1)th layer at the interface between (k-1)th and kth layer is given by

$$b_{k-1}(t_j) = \Gamma_{k-1,k}\, a_{k-1}(t_j) + T_{k,k-1} b_k(t_j) \quad (1)$$

Where $a_{k-1}(t_j)$ is the incident wave, $\Gamma_{k-1,k}$ and $T_{k,k-1}$ are the reflection and transmission coefficients, respectively. The reflected field at the interface in the kth layer is given by

$$b_k(t_j) = \sum_{n\ \text{odd}} A_n(k) b_k(t_{j-n}) + \sum_{n\ \text{even}} A_n(k) a_k(t_{j-n}) \quad (2)$$

Where $A_n(k)$ are functions of medium parameters in the kth layer, which represent different orders of internal reflections. When the propagation velocity is assumed constant, the medium in each layer can be represented by three parameters Z_{ok}, S_k and D_k. Z_{ok} is the characteristic impedance, S_k and D_k describe the attenuation and distortion characteristics of the medium, respectively. Starting from the sending end boundary where the incident and reflected fields are measured, inversion is achieved by solving equations (1) and (2). These equations contain three unknown medium parameters which can be determined in principle from three sampled values of incident and reflected fields at the boundary at different times. However, $A_n(k)$ are transcendental functions and equations (2) may possess infinite number of solutions. The numerical problem is associated with choosing the appropriate solution among them. It can be shown that when $S_k\tau << 1.0$, where τ is the sample period, the inversion is unique. This condition can be used to advantage in numerical computation for arbitrary S_k by choosing a sufficiently small τ.

In practice, signals are contaminated with noise. More measurements on the incident and reflected waves may be used to reduce inversion errors. In this case, there are more equations then unknowns; this over stated problem can be solved by minimizing the sum of square deviations. A computer algorithm is discussed and simulated results will be shown.

ON SOME ASPECTS OF MICROWAVE IMAGING.

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This communication is dealing with imaging objects from amplitude and phase records of the diffracted field on a surface of finite extent. Finite extent means here dimensions of the order of 10 wavelengths. The proposed method is based on a numerical reconstruction of the image by transforming the intercepted divergent diffracted beam into a convergent one. This transformation, similar to usual near field - far field transformations, not only provides plane images of 3-dimensional bodies; it also provides, to some extent, tomographic views of such objects. The numerical simulation of the image formation process presents a large versatility. The quality of the process expressed, as for the optical case, in terms of axial field depth or transverse resolution is related to the dimensions of the surface over which the diffracted field is measured. The usefulness of such images is largely conditionned by the rapidity of the diffracted field measurements. Allready available techniques are now well suited [Le Radant : nouveau procédé de balayage électronique, Y. MICHEL, R. PAUCHARD, P. VIDAL, Onde Electrique, 1979, vol 59, n° 12, pp 89-94] for fast records without any probe displacement.

CHARACTERIZATION OF A CYLINDRICAL SHELL.A GEOMETRICAL OPTICS APPROACH TO AN INVERSE SCATTERING PROBLEM.

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The field scattered by a cylindrical shell of circular cross section, illuminated by a plane wave, is computed in the backscattered direction using two different formulations. The first one is rigorous and based on modal expansion of the fields; the second one is approximate and uses geometrical optics and ray theory. When the observation point is on the axis of propagation, two rays are needed and the approximate theory shows that the variations of the field against frequency presents a double periodity. This agrees in a good manner with the rigorous solution if the shell impedance is approximatively less than 1.3. From the measurement of these periodicities we were able to determine the impedance and the thickness of the shell assuming known its outer radius b. This method was applied to the acoustic probing of blood vessel and the impedance obtained was Z = 1.11 compared to the one found in the litterature Z = 1.09; the discrepancies are acceptable.

When the observation point moves on a plane perpendicular to the direction of propagation of the incident wave (but still in the backscattered region), at most four rays are necessary to describe the total field. In some regions, two rays are necessary and similar results can be obtained for the impedance. In this case fields are computed at one frequency and on an interval of length less than 4b.

In both cases, the method was used when the inner medium of theshell is different from the surrounding one (blood filling the vessel) and the impedance of this medium was also obtained.

INVERSE SCATTERING - INVERSE SOURCE THEORY

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Treated is the inverse scattering inverse source problem associated with the inhomogeneous Helmholtz wave equation, the (special case) Sturm-Liouiville (acoustic wave) equation, and the time-independent Schrodinger equation. To this end, the concepts of a reference wave velocity, and an associated free reference space Green's function spectrum, are introduced. A modified Kirchhoff surface integral, containing only the gradiant of the real part of this free reference space Green's function spectrum and the fields on a measurement surface, is formulated, yielding an integral equation for the unknown fields and sources in the interior of the closed surface on which the (remotely sensed) fields are known. A well-posed, analytic closed form solution of this integral equation for the unknown fields and their Laplacean is obtained with the aid of a (modified) spatial Fourier transform in which the reference velocity is continually varied in such a fashion that the Ewald sphere shell sweeps to fill the entire transform space. The unknown potential or medium properties, and the unknown sources, are then determined algebraically for the inverse scattering and inverse source problems respectively. The effects of finite sampling density and incomplete observation domain are discussed briefly. Preliminary numerico-experimental results are presented.

AN EXACT, CLOSED-FORM SOLUTION FOR THE SOURCE TERM IN THE INVERSE SOURCE/INVERSE SCATTERING PROBLEM, AND AN ANALYTIC SOLUTION FOR THE SCATTERING POTENTIAL

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A new, analytic closed-form solution to the Bojarski Exact Inverse Scattering Theory has been obtained as presented in a companion paper. This solution provides an expression for the total field, including the field in the source region, in terms of the measured data. To obtain the source term in the inverse source problem it is necessary to take the Laplacean of the solution, as shown by Bojarski. This paper shows that by making a simple transformation of coordinates and applying the new solution it is possible to obtain a well-posed, closed-form analytical solution for the sources. The solution for the source term is derived, and, although not initially obvious, it is shown that this solution is the same as the value obtained by applying the Laplacean to the solution for the field. The form of the solution for the source is such that additional insight is gained into the physical implication of these solutions to the inverse scattering problem. The direct solution for the source term is extremely important from a practical standpoint, because it has the crucial property of avoiding taking derivatives of noise-contaminated measured data. These properties are discussed.

When the inverse scattering problem is expressed in terms of the scattering potential of the scatterer, it is sometimes this potential which is sought. Using the solution for the sources, an exact, closed-form, analytic solution for the potential is derived. This has important implications for the classical quantum mechanics scattering problems, as well as for field theory in general. These implications are discussed.

UNIQUENESS, WELL-POSEDNESS, AND "REAL WORLD" CONSIDERATIONS FOR AN ANALYTIC, CLOSED-FORM SOLUTION TO THE INVERSE SCATTERING PROBLEM

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A new, analytic closed-form solution to the Bojarski Exact Inverse Scattering Theory has been obtained. This solution to both the inverse source and inverse scattering problems is analogous to the role played by the Kirchoff and Stratton-Chu equations in the direct scattering problem. Prior to this solution, it was necessary to solve the integral equation resulting from the Exact Theory by numerical deconvolution techniques. A substantial body of results relating to uniqueness, well-posedness, computational efficiency, the effect of measurement noise, and the effects of incomplete, sampled measurements has been obtained using this integral equation. This paper reexamines these results in light of the new closed-form solution. The questions of uniqueness and computational efficiency are answered directly by the form of the new solution. However, portions of the derivations of the other results depended on the particular form of the numerical solution. It is shown that the new solution permits much more general, and in some instances, stronger statements of most of these results to be made.

THE APPLICATION OF THE EXACT, CLOSED-FORM SOLUTION TO THE INVERSE SCATTERING PROBLEM TO THE REMOTE PROBING OF INHOMOGENEOUS MEDIA

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A new, analytic closed-form solution to the Bojarski Exact Inverse Scattering Theory has been obtained. Previously, Stone has discussed the additional steps necessary to apply inverse scattering theory to the remote probing of inhomogeneous media: The steps necessary to go from the solution to the inverse source problem to the solution to the inverse medium problem. These results are reexamined in the light of the new, closed-form solution to the inverse source problem. It is shown that, for a certain, rather general class of problems, an analytic solution expression for the complex refractive index as a function of three spatial dimensions can be obtained. This expression is derived, and its properties from the standpoint of "real-world" remote probing are explored.

The conclusions reached are demonstrated by application to the problem of determining the three-dimensional distribution of electron density in the ionosphere using a satellite-borne radio beacon as a probe. The results of numerical simulations of such an experiment, utilizing the new solution, are presented.

SESSION B-8 TRANSIENTS AND SEM
THURSDAY 1:30 - 5:00
SAN GABRIEL, Room A

Chairman: C.L. Bennett
Sperry Research Center
Sudbury, MA

VOLTERRA SERIES SOLUTION OF MAXWELL EQUATIONS
IN NONLINEAR MEDIA

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The Volterra series has been extensively used in communication theory (nonlinear noise filtering, E.Bedrosian and S.O. Rice, Proc. IEEE, 59, 1688-1707, 1971) and lumped circuit analysis (nonlinear distortion and cross-modulation, J. Bussgang et al., Proc. IEEE, 62, 1088-1119, 1974). In the field of electromagnetics it has been applied to the computation of the harmonic response of antennas with lumped nonlinear loads (G.Franceschetti and I.Pinto, in Nonlinear Electromagnetics, P.L.E. Uslenghi ed., New York, 1980). The Volterra series shows a very appealing feature: the n-order nonlinear response is computed as the n-fold convolution between the forcing input and a properly defined n-order impulse response in the Wiener sense.

We extend the Volterra series formalism to EM transient propagation and scattering problems in nonlinear media, thus considering space-time vector fields instead of harmonic scalar functions.

This extension proceeds as follows: the equation(s) of motion of (electric) charges and (magnetic) dipoles in the medium are solved in terms of a Volterra series, thus obtaining the nonlinear constitutive relationships. These, in turn, are used together with Maxwell equations for obtaining the nonlinear Volterra-Green functions (G.Franceschetti and I.Pinto, Proc. of the 3rd Nat.l Meeting of Applied EM.tics, Bari (Italy), 1980, AN-7). As an application, we investigated a periodically nonlinearly loaded transmission line; a pulsed nonlinearly loaded antenna; harmonic scattering by a nonlinear ferrite cylinder; pulse transmission through a nonlinear plasma slab.

We have further obtained a number of preliminary results concerning the convergence and truncation properties of the series; analytical prolongeation; secular terms and renormalization techniques; and formulation of general EM theorems (Poynting, reciprocity, equivalence, uniqueness, etc.) in the presence of nonlinear media. A new result (which includes that of A.Yariv, IEEE J. of Quantum Electron., 13, 943-950, 1977) is the close connection between Volterra kernels computation and Feynman graph techniques.

THE NATURAL FREQUENCIES OF THE AXISYMMETRIC TE MODES OF A HOLLOW CONDUCTING SPHERE WITH A CIRCULAR APERTURE

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The hollow conducting spherical shell with a circular aperture represents a canonical cavity-backed aperture geometry. By virtue of its separable shape, this geometry is amenable to a primarily analytical treatment. The simplest special cases, and the first to be considered, are those in which the electromagnetic field is symmetric about the sphere-aperture axis. In these cases, pure TE and TM modes can exist; we present the results for the axisymmetric TE modes in this paper.

The electromagnetic problem is initially formulated as a pair of dual series equations. These are then converted to a Fredholm integral equation of the second kind, whose eigenvalues yield the natural frequencies of the structure. The integral equation is solved by converting it into a set of linear equations for the expansion coefficients in the original dual series equations. This system of linear equations is then solved numerically.

Data are presented to illustrate the migration of the natural frequencies in the complex s-plane as the aperture opening angle is varied. Approximate formulas are also given to describe the "internal" mode Q's when the aperture is small.

POLE EXTRACTION IN THE FREQUENCY DOMAIN

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An investigation has been carried out to determine the feasibility of extracting the SEM (singularity expansion method) poles of a scattering body in the frequency domain. An iterative numerical algorithm has been developed which curve fits a rational function to the frequency response ($f_1 \le f \le f_2$) of a scattering body with equal weighting at all frequencies. The poles and residues of the rational function are then computed.

The numerical process has been applied to the surface field at a perfectly conducting sphere for which the poles, residues, and fields were calculated to six decimal places from the Mie series. For a frequency range inclusive of the first N (≤ 5) complex conjugate pole pairs, an excellent fit can be achieved with a rational function containing a denominator polynomial of order approximately equal to 4N. Fitting the fields at another position on the sphere enables the positionally invariant SEM poles to be separated from the remaining poles of the rational function. The extracted SEM poles and residues are in good agreement with the known values. However, the accuracy of the extracted SEM poles progressively decreases as the data is rounded to fewer decimal places, with the higher order pole locations deteriorating first and most rapidly. For data accurate to one percent, only the dominant pole pair can be located with sufficient accuracy to determine the positional dependence of the residues, yet the curve fit remains excellent. Similar results are obtained when modest amounts of noise are added or when experimentally measured surface fields are employed.

PHYSICAL BASIS OF THE SINGULARITY EXPANSION METHOD IN TERMS OF CREEPING WAVES (THEORY AND EXPERIMENT).

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The Singularity Expansion Method (SEM) describes the echo return from pulsed radar signals as a Prony-series superposition of sinusoids which are due to poles in the complex frequency plane. For the case of conducting spheres and cylinders, we show that these poles can be regrouped into infinite subsets, each representing a given creeping wave (W. Franz, Naturf. A9, 705, 1954), with the nth pole in the series corresponding to n wavelengths of a standing wave spanning the circumference. The corresponding Prony sub-series, and thus the Prony series itself, then appears simply as a mathematical device which synthesizes particular creeping waves. Dispersion and absorption curves of the latter are obtained. An experiment carried out at NSWC Dahlgren on bistatic radar pulse scattering from conducting spheres, cylinders, and cones exhibits the creeping waves, with phase velocities comparable to the theoretical ones when a suitable average over the incident pulse spectrum is performed. The pulse distortion obtained from the calculated dispersion and absorption curves is also verified experimentally.

PRACTICAL SOLUTIONS TO TRANSIENT ELECTROMAGNETIC PROBING OF STRATIFIED LOSSY MEDIA

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Previous studies have shown the possibility of lossy stratified media probing by analysing the field they reflect when there are illuminated by plane wave of arbitrary time dependance.

This paper deals with some practical problems associated with the application of these reconstruction processes to realistic situations. More particularly, the following points are examined :

1) The limitation of the observation depth due to the "screening" effect of conducting layers. An original solution based on a TEM mode perturbated by the medium to be investigated is proposed. This solution increases by a factor 10 or more the observation depth and allows a separate reconstruction of permittivity and conductivity profiles.

2) The production of a transient plane wave of finite extent. Grounded horns are shown to constitute a good solution for locally simulating the ideal infinite plane wave illumination, at least in the case of lossy media.

3) The influence of possible variations of the permittivity and the conductivity with frequency. For the sake of simplicity, such variations have been neglected in the reconstruction process. The validity of this approximation is discussed.

IDENTIFICATION OF SCATTERER RESONANCES BY REVERSING THE MEASURED UNFORCED RESPONSE IN TIME

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Least-squares Prony's method has worked well in the identification of natural resonances or poles of a scatterer by operating on their numerically-generated time-domain responses. Poor pole estimates appear, however, when the method is applied to the noise-contaminated responses that might arise in applications such as radar target identification via transient returns.

Numerous modifications to Prony's method that are intent upon alleviating the problem with noise have been investigated of which none are completely successful. One such technique, the technique of increasing the order of Prony's method until the waveform is adequately modeled, is examined in this paper. The technique has the advantage of improved pole estimates but also introduces the new problem of distinguishing between the extraneous poles that model the noise and the true poles that carry scatterer information.

Specifically, the discussion concentrates on a technique for alleviating this new problem. The technique consists of applying least-squares Prony's method to both the original transient response and the time-reversed version of the response. The true poles tend to be negated or reflected through the real axis in the s-plane when the response is reversed. The extraneous poles, however, are not negated but tend to remain unchanged due to the uniform nature of noise under time reversal. Thus the true poles may be distinguished. Numerical results and guidelines for the effective use of least-squares Prony's method in this regard are presented.

DATA ACQUISITION AND PROCESSING IN TRANSIENT SCATTERING MEASUREMENTS:

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The development and operation of a new transient scattering facility at NPS are described. Initial consideration is given to the design and fabrication of the ground plane, antennas, and targets. The measurement technique uses the principles of signal averaging and superposition to extract the transient signature. Further on-line signal processing is discussed which employs FFT and optimal digital filtering methods for the synthesis of the ramp response of the target. The utilization of this processed data for the investigation of both direct target imaging and Prony-type identification procedures is addressed.

TRANSIENT MEASUREMENTS OF LINEAR ANTENNA ARRAYS IN FREE SPACE AND OVER PERFECTLY CONDUCTING GROUND

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During the last decade the transient behavior of scatterers is a major object of theoretical discussion. However, the interaction and coupling phenomena between different scattering objects are not completely solved.

Analytical and numerical techniques especially those based on SEM (C.E. Baum, Airforce Weapons Laboratory Interaction Note 88, Dec. 1971) give a physical insight. We developed a modal interaction scheme which allows simple analytical computations of the interaction of antennas (K.J. Langenberg, K.D. Rech, Proc. European Microwave Conference, Rome, 1976). Starting from these techniques the transient behavior of LPDA-Antennas was calculated in free space, and the transient resonance characteristics of these antennas were determined for perfectly conducting and lossy ground with numerical means (K.D. Becker, K.J. Langenberg, K.D. Rech, URSI Conf. Proc., Munich, 1980)

Based on these theoretical SEM-investigations we will show parametric transient and monochromatic experimental studies of the input current, electric nearfield and farfield of linear antennas and antenna arrays. The transient and monochromatic results are compared and SEM quantities as far as possible extracted. Especially we shall investigate the influence of antenna thickness on current, field and resonances. The transient and monochromatic coupling effects in two element arrays under variation of element spacing length and diameter are presented. The interaction for a three element array and finally the transient resonance behavior of a five element LPDA are discussed.

SURFACE CURRENTS AND CHARGES OF AN AIRCRAFT WITH A REFUELING TANKER

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ABSTRACT

Aircraft in-flight refueling is one of the important operational modes as far as vulnerability and survivability are concerned. A number of predictions have been made in the past in terms of the surface current and charge of an aircraft in refueling mode. Experimental measurements were considered not feasible due to the limitation in size for the existing facilities, excluding the case of using scale model aircrafts. As a result of the completion of a newly constructed transient electromagnetic field simulator, a series of measurements were made on the surface current and charge of the aircrafts in refueling mode. These data enable us to make a direct comparison with the prediction based on the standard method-of-moments computer code applied to the aircraft modeled in a wire mesh form. These comparisons show that the theoretical model indeed provides excellent predictions for the induced currents and charges on the aircrafts.

SESSION B-9 NUMERICAL AND ANALYTIC TECHNIQUES
THURSDAY 1:30 - 5:00
SANTA BARBARA, Room B

Chairman: D. Wilton
University of Mississippi
University, MS

OPTICAL WAVELENGTH CALCULATION OF SCATTERING CROSS SECTIONS WITH THE NUMERICAL ELECTROMAGNETIC CODE (NEC)

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The total scattering, absorption, and extinction cross sections and the radar cross sections for five generic geometries of thin wire scatterers (including the simple dipole) were calculated using the Numerical Electromagnetic Code (NEC). The cross sections were determined for random incidence of linearly polarized plane waves and with a scatterer length to wavelength ratio ranging from $L/\lambda = 6/1000$ to $L/\lambda = 6/1$ where L = 6 micrometers. The cross sections were also calculated as functions of the conductivity of the scatterer and as functions of the scatterers' length to diameter ratio.

The total cross section calculation is a new addition to NEC and the modifications required and verification of the new code is detailed in this paper. Good agreement is obtained with NEC in comparison to limiting cases where other solutions exist.

QUADRIFILAR HELIX ANTENNA DESIGN FOR SATELLITE COMMUNICATIONS USING THE NUMERICAL ELECTROMAGNETIC CODE

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The Numerical Electromagnetic Code (NEC) was used to design two quadrifilar helix antennas for satellite communications. One antenna was for transmitting and one for receiving. Each antenna is a resonant, fractional-turn, quadrifilar helix with antiphase feed (called "volutes"). The volute is well suited to this application because of the cardioid-shaped circularly polarized pattern.

NEC is a computer code developed for the Government which uses moment method techniques for analyzing the electromagnetic response of an arbitrary structure consisting of wires and surfaces in free space or over a ground plane. Before NEC was used to design the volute for two-way satellite communications, it was used to model a previously designed volute antenna. The calculated results, which compared favorably to the previous measurements, established confidence in using NEC to design a new antenna. The pattern comparison at 302.7MHz was extremely good with an agreement of better than 2dB in the upper hemisphere. The input resistance to one of the two pair of feed arms was calculated as 0.7 ohms which transforms to 91.4 ohms by a quarter wave matching transformer with a characterisitic impedance of 8 ohms. The measured value was approximately 50 ohms at the input to the matching transformer; however, the difference is probably caused by difficulties in modeling at such low radiation resistances.

A model of the transmitting antenna designed using NEC was constructed and measurements taken. Excellent agreement was obtained for the free space patterns and impedances from 290MHz to 310MHz. The measured gain was 2dBic, which compares favorably with the calculated gain of about 4dBic when the mismatch loss in the measurements is taken into account. The transmitting volute was a one half wavelength (at 302MHz), one half turn with a 4.5 inch diameter. The receiving volute has not been constructed.

The NEC program is also valuable for predicting the vertical field patterns of the volute operating at various heights above sea water. This pattern information has heretofore been unobtainable.

A NEW LOCAL-FILE MANIPULATION TECHNIQUE FOR SOLVING THE SCATTERING OF LARGE OBJECTS

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Numerical solution of electromagnetic problems by the moment method is limited by the speed and central memory of existing digital computers. Techniques to extend the effective memory of the computer to handle large problems include the extended memory (hardware), virtual memory and banded matrix iteration (softwares). These techniques invariably involve complex and repetitive processes, resulting in prohibitively long execution time rapidly increasing with the size of the matrix. For example, on a CDC Cyber 74 machine, the solution of a 40,000 element matrix by the virtual memory technique requires about 8,000 CPU seconds--one hundred times the CPU seconds needed in solving this problem using central memory above.

A new technique has been developed to store the matrix in four local files, each of which is allocated a certain disc space. Blocks of matrix elements are stored with a "write" statement in the local disc files. These are also "read" in blocks from the local files for use in the matrix solution. This storage and transfer of matrix element in blocks or groups is essential to the efficiency of the present technique. The solution of the matrix is by the lower-upper decomposition method. When applied to the computation of the scattering of dielectric objects, the execution time needed in the local-file manipulation technique is about halfway between the virtual memory technique and the conventional central memory technique.

TWO HYBRID TECHNIQUES FOR THE TREATMENT
OF WIRE ANTENNAS NEAR AN ELLIPTIC CYLINDER

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Thessaloniki, Greece

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Xanthi, Greece

and

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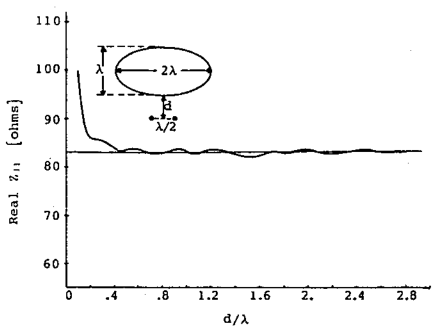
Presented in this paper are two hybrid techniques for combining the method of moments (MM) with other techniques. Both hybrid techniques treat the problem of a thin linear antenna near an elliptic cylinder. The principle aim of this paper is to combine the method of moments treatment of wire antennas with the eigenfunction solution for an elliptic cylinder. The results are then verified using the hybrid moment method-GTD technique.

In the MM-eigenfunction technique the generalized impedance matrix for the wire antenna is calculated in the usual manner. This matrix is then augmented with the matrix [ΔZ] whose terms represent the interaction between the antenna and the elliptic cylinder. To compute this interaction one uses the field radiated by the elliptic cylinder as given by the eigenfunction solution.

Results will be shown for the input impedance of arrays of dipoles near an elliptic cylinder as well as for a single dipole. For arrays, results for the mutual impedance will also be shown. For example, the figure below shows the real part of the mutual impedance between two half-wave dipoles separated by λ/2 in the presence of an elliptic cylinder having a 2:1 axial ratio.



A HYBRID FD-TD APPROACH TO ELECTROMAGNETIC WAVE BACKSCATTERING

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General electromagnetic wave backscattering problems have been difficult to treat with analytical and/or numerical methods because of the complicating effects of curvatures, corners, edges, apertures, and dielectric loading of structures. In the frequency regime of structure size between 0.1λ and 10λ, it has been necessary to use canonical structures, rather than realistic models, in an attempt to gain insight into backscattering mechanisms using analytical and method-of-moments (MoM) numerical approaches. A potentially powerful alternate approach is the (FD-TD) Finite Difference-Time Domain Method (A. Taflove, "Evaluation of Time Domain EM Coupling Techniques", RADC-TR-80-251, August, 1980) which allows the computation of internal and external near fields by direct modeling of realistic structures.

In order to treat the realistic backscattering problems more effectively, a new hybrid technique has been developed which involves combining the FD-TD method with a near-field to far-field transformation using field equivalences. In the hybrid technique, the backscattering problem is analyzed in two steps by treating the relatively complex near-field and the relatively simple far-field regions separately. The method involves first, determination of equivalent electric and/or magnetic currents in the vicinity of the scatterer of interest using FD-TD for a given external illumination. The computed near-field currents are then integrated to derive the far-field backscattering pattern and radar cross section. Since the FD-TD method can deal with dielectrics, permeable materials, inhomogeneous materials, and anisotropic materials in a natural manner, it is thus possible to incorporate much detail of the physics of the wave interaction with the complex scatterer of interest.

Using the FD-TD method, the computed surface electric current distribution (and near electric and magnetic fields) will be presented for resonant-regime rectangular metal objects subject to plane wave illumination at broadside and oblique angles of incidence. These currents and fields will be compared to MoM computed results. The far backscattered field pattern and radar cross section will then be derived from the FD-TD data, and compared to results obtained using the MoM approach. It will be shown that a very high degree of accuracy is obtained using the hybrid FD-TD approach.

FFT UTILIZATION IN MOMENT METHOD SOLUTIONS USING ENTIRE DOMAIN BASES

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A. Q. Martin, Electrical Engr. Dept., University of Mississippi, University, Mississippi, 38677.

The Fast Fourier Transform (FFT) algorithm has made feasible the use of entire domain functions (EDF) as expansion set components in moment method solutions. Traditionally, serious limitations have been associated with use of EDF in moment method solutions. The limitations are, in general, excessive matrix fill time (and cost) and ill-conditioned matrices due to large off-diagonal matrix elements. Matrix fill time is prohibitive for EDF because the convolution integral which defines the matrix elements must be evaluated over the entire range of the body. Combined use of the FFT (as opposed to numerical integration), transform techniques, and EDF provides, in a highly efficient manner, computation of matrix elements at a large number of field points. Due to the large number of matrix elements available, an overdetermined system of equations result. Use of "psuedo-inverse" methods for the solution results in a total scattered field with a least-squares error, which was found to be much less than that obtainable through direct moment methods with point-matching.

An investigation of matrix techniques versus optimization methods to determine the unknown coefficients was made and "psuedo-inversion" proved superior to optimization. More sophisticated matrix techniques (like Gaussian elimination) will yield additional efficiency. In addition, the scattered far field can be very easily computed since transforming the EDF is a necessary intermediate step in the procedure, and the far field is directly related to the Fourier transform of the current.

The FFT-EDF method was applied to a two dimensional strip scatterer. For both TE and TM plane wave scattering, the technique showed excellent agreement with moment method subdomain solutions. Use of EDF (as compared to moment method subdomain solutions) effectively reduced the number of expansion set components necessary to represent the induced current when all components incorporated the proper edge behavior. Inherent in this technique, however, are the problems associated with obtaining a "good" transform of the Green's function.

A MOMENT SOLUTION OF THE DIFFUSION EQUATION USING MEASURED BOUNDARY CONDITIONS

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Using measurements of the axial magnetic field at the boundary, all the fields interior to an induction furnace are calculated by the Galerkin method. The measured and calculated axial magnetic fields agreed within 2 percent and 3 degrees of phase throughout the volume. The radial magnetic fields also showed good agreement. A scale model of the furnace was constructed with mercury and an audio oscillator and amplifier. The furnace diameter is 3.2 skin depths.

APPLICATION OF THE CONJUGATE FIELD MATCHING TECHNIQUE TO REFLECTOR ANTENNAS -- A CRITICAL REVIEW*

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Ever-increasing demand for the design of multiple beam antennas has guided investigators to employ a variety of techniques for improving the off-axis performance of the antennas. Among these techniques, the concept of "conjugate field matching" has recently attracted much attention both in the areas of electromagnetics and optics. Simply stated, the aperture field of the antenna feed is conjugate matched (E*,-H*) to the aperture field of the feed (E,H) when the reflector is illuminated by a plane wave. It is widely believed that if this conjugate matched field can be simulated, then the antenna demonstrates a remarkedly improved performance for off-axis beams. There is, however, no rigorous vectorial proof to substantiate this observation. In this paper, based on the application of general reciprocity formulations, the concept of conjugate field matching is formulated from a vectorial viewpoint. It is shown that the concept only applies for a fixed state of polarization and direction of the incoming plane wave. Furthermore, it is demonstrated that, although the technique improves the gain and efficiency in the plane wave direction, it does not necessarily provide any insight into either the sidelobe or the cross-polarized pattern characteristics. The generalization of the technique to non-plane wave cases and for both single and dual reflectors will also be presented.

*This work was supported by NASA under contract NAS 7-100.

†S. W. Lee is with the University of Illinois, Urbana, and is a consultant to JPL.

THE BEST LEAST SQUARES RATIONAL APPROXIMATION OF TRANSFER FUNCTIONS BY SOLUTION OF A LINEAR UNCOUPLED EIGENVALUE PROBLEM

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In published literature several technique exist to approximate transfer functions by a ratio of two polynomials from the input and output waveforms. Let the sequences $\{x_1, x_2 \ldots, x_N\}$ and $\{y_1, y_2 \ldots, y_M\}$ represent the sampled input x(t) and output y(t) of the system characterized by h(t). In other words, if X(z) and Y(z) are z-transforms of the input and output waveforms then

$$X(z) = x_1 + x_2 z + x_3 z^2 + \ldots + x_N z^{N-1}$$

and

$$Y(z) = y_1 + y_2 z + y_3 z^2 + \ldots + y_M z^{M-1}$$

We want to approximate H(z), the transform of h(t) by

$$H(z) = \frac{b_1 + b_2 z + \ldots + b_p z^{p-1}}{a_1 + a_2 z + \ldots + a_q z^{q-1}}$$

where a_i and b_i are the unknowns to be solved for. A non iterative technique is presented for the best least squares approximation of transfer functions by the ratio of two polynomials. the best least squares coefficients $\{a_i\}$ and $\{b_i\}$ are obtained from the solution of an eigenvalue equation. It will be shown that solution of the best coefficients $\{a_i\}$ and $\{b_i\}$ are symmetric with respect to the other set of parameters. Thus this method yields a set of uncoupled linear equations in terms of the unknown parameters. Examples will be presented to illustrate its use.

A second objective of this presentation is to show that when noise is present the coefficients $\{a_i\}$ and $\{b_i\}$ will be automatically biased. It will be shown that this is a best least squares extension of the autocorrelation version of Prony's method. However the problem with this technique is that even though the coefficients $\{a_i\}$ are the best least squares solutions, the poles, which are obtained by the roots of the denominator polynomial are not guaranteed to be in the LHP.

SESSION B-10 ANTENNAS I: REFLECTORS AND RADOMES
THURSDAY 1:30 - 5:00
SANTA BARBARA, Room A

Chairman: Y. Rahmat-Samii
Jet Propulsion Laboratory
Pasadena, CA

SOME LIMITATIONS IN THE BROADBAND OPERATION OF SEGMENTED REFLECTORS

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Abstract

Arrays of finite conducting linear elements are often used to approximate solid reflectors in applications where weight and windloading make it impractical to use large, solid surfaces. A common configuration for such an array is simply to connect the centres of the linear elements by a single structural member such that the reflector is an array of parasitic dipoles excited by a driven element located in front of the reflector. Theoretical and experimental data obtained for several plane, corner and parabolic reflector configurations show that distinct resonances, characterized by narrowband fluctuations in the radiation pattern and input impedance, may seriously affect the operation of these antennas. Adjustment of the reflector element length and spacing provides an effective means of controlling these resonances.

BEAM-BROADENING TECHNIQUES FOR HIGH-GAIN REFLECTOR ANTENNAS

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The design of large communication antennas for space often requires secondary beamshapes that are broader than the beamshape produced by "optimum" efficient illumination of the main reflector. The most efficient (and usually most narrow) beam generally services a direct-to-user system, while the broader beam(s) service an area where the lower gain is compensated by larger ground terminals in a trucking system. This paper addresses techniques that can be used to broaden the secondary beams of reflector antennas. These techniques utilize single, simple feed horns; array feeds; and dual-shaping of the subreflector and main reflector.

In order for the secondary beam of a reflector antenna to be broadened, the effective diameter of the main reflector must be reduced, or, out-of-phase illumination energy must be introduced on the main reflector. The effective diameter may be reduced by underillumination of the reflector, i.e., using a directive feed. This produces for instance, a completely tapered illumination in the aperture of the reflector. The completely tapered illumination produces a broader than normal beam but the amplitude taper efficiency is lowered. This is anticipated from a gain-beamwidth product standpoint. However, the overall efficiency of the antenna system will essentially remain constant since spillover is reduced as a result of the more directive feed.

If a very directive feed is used, the first sidelobe will place out-of-phase energy on the reflector. This out-of-phase energy can be used to produce large changes in beamwidth, which can be up to three or four times the normal beamwidth of the antenna system. The result of this type of beamwidth broadening is much lower amplitude and phase efficiencies. Spillover can not compensate for these higher losses and as such the total aperture efficiency is less. Again, this can be anticipated from the gain-beamwidth product.

The technique of beam-broadening can be applied to most reflector antennas. Beam-broadening can be used to meet gain/beamwidth requirements where reflector size is specified or other constraints limit usual design methods. Although several techniques are viable, particular application of a technique will depend on the specific antenna requirements.

Phase Error Analysis in Communications Antennas

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Recent analyses of phase error due to cone or pyramid apex offset in a horn-reflector antenna show an interesting result. The phase error for a given type of feed offset is of a different characteristic in horn-reflectors than in the center-fed parabolic reflector antenna. In parabolic dish antennas, it was early realized (H. T. Friis and W. D. Lewis, "Radar Antennas" in Radar Systems and Components, D. Van Nostrand Co., Princeton, p. 785, 1949) that an offset of the feed in lateral direction, that is, toward the dish from the focal point or away from the dish, caused a convex or a concave phase front from the aperture of the dish. It may be easily seen by ray tracing that in or out movement of the feed produces convex or concave phase fronts, respectively. The effects of these phase errors have been extensively analyzed (H. Jasik, Antenna Engineering Handbook, McGraw-Hill, New York, pp. 2-30 to 2-36, 1961, and S. Silver, Microwave Antenna Theory and Design, McGraw Hill, New York, pp. 186-192, 1947). In addition, transverse movement of the feed has often been analyzed and even employed to advantage (K. S. Kelleher, Antenna Engineering Handbook, McGraw-Hill, New York, pp. 15-20 to 15-21, 1961). The major effect of transverse movement is the tilting of the phase front in a linear fashion accompanied with a small reduction in gain which is usually negligible.

In horn-reflector antennas, however, it is found that these effects are, to a first order approximation, essentially reversed for the two types of feed offset discussed above. Consider a full paraboloid of revolution and note that the horn-reflector antenna occupies only a segment of this surface evenly disposed about a point vertically above the focal point. The effect of transverse feed offset on phase error is quite linear until the region occupied by the reflector segment of the horn-reflector is reached, but the phase behavior within the aperture of the horn-reflector is non-linear, and is, in fact, convex. The relative phase error, however, is small in this region and relatively large offsets of grater than 1% of the focal length are necessary before objectionable phase error effects are accrued for the highest frequency now used in terrestrial radio relay systems. Finally, it is noted that offsets in the direction called lateral above, produce very small phase errors with a mainly linear characteristic.

MULTIPLE SCATTERING CONTRIBUTIONS OF MULTIPLE CIRCULAR CONDUCTING CYLINDERS TO ANTENNA GAIN LOSS

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Previous gain loss analysis of directive antennas has included only contributions from independent scattering obstacles (Cown, Moore and Ryan, 1978). This paper extends the previous research to include multiple scattering contributions which can be appreciable if the obstacles are electrically near one another. Analysis of the multiple scattering which predicts the far-field gain loss due to two-circular conducting cylinders placed in the near zone of a directive antenna is discussed. Computed gain loss is compared with measured gain loss data for various diameter cylinders located in the near zone of a parabolic antenna operating at a frequency of 5.5 GHz.

Multiple scattering contributions are included by using an analysis based on an approximate formulation developed by Zittron and Karp, 1961. This method has been shown to predict scattering cross-sections in good agreement with an exact formulation even when the cylinders are electrically close to one another. (Kohei Hongo, IEE Trans. AP-26, No. 5, 1978). The aforementioned method is used to define a plane wave scattering operator for the two cylinders. This plane wave operator and the calculated plane wave spectrum of the antenna are then used in a Plane Wave Spectrum scattering analysis to calculate the far-zone scattered field of the two cylinders. The antenna gain loss is then calculated using the forward scattered field and known forward radiated (boresight) far-field of the antenna.

The measured data was obtained using a paraboloidal dish antenna, four feet in diameter, fed by a flared waveguide horn. The data was taken for 6-inch, 14-inch, and 24-inch diameter cylinders located in the antenna's near-field with varying center-to-center inter-obstacle separations in the range of 22 to 42 inches. The cylinder separations were varied in approximately .50-inch steps. Gain loss as a function of azimuth angle was then measured for each separation.

GUIDED WAVES & THEIR CONSEQUENCES FOR RADOME ANALYSIS & PERFORMANCE

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Despite recent progress, accurate radome analysis remains a problem because the variables are many and range widely. Although several numerical methods have been developed, comprehensive experimental evaluations are lacking. Most methods treat the radome as locally flat to utilize transmittance formulas for plane waves incident on flat dielectric sheets. The moment method is an exception, but it has only been applied to two dimensional or small radomes.

This paper describes measurements and moment method calculations of phase and intensity in radome-bounded regions. These data are factors in integrands of diffraction integrals for farfield patterns and thus are the basis for radome analysis. These wavefront data have been directly analyzed to determine angle of arrival. These data are a direct test of the accuracy of approximate propagation description.

The data are for hollow ogival radomes, for hollow curved wedges, half a curved wedge, and flat slabs. Evidence is found for slab guided waves — even for the curved wedge and the axially symmetric shell. These guided waves produce deep transmittance minima as much as 18 dB below the intensity of the incident field. The effects are especially pronounced for frequencies in which the dielectrics are not a half wave thickness. The transmittance variations were reduced by applying low dielectric constant layers, similar to claddings for optical fibers.

RIGOROUS ASYMPTOTIC ANALYSIS OF TRANSMISSION THROUGH A CURVED DIELECTRIC SLAB

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A circularly curved homogeneous dielectric layer forms the simplest prototype for analyzing the transmission properties of dielectric radomes that shield an aperture field. In the present study, fields in such a layer environment are excited by an axial line source located arbitrarily on the concave side, and the transmitted field is evaluated anywhere on the convex side. A rigorous contour integral representation for a "partial" Green's function is derived that contains all of the information essential for determination of the transmission properties of an angular section of the layer. This partial Green's function differs from the Green's function for a complete dielectric tube by removal of the azimuthal periodicity through extension of the azimuthal co-ordinate range to infinity. Spurious diffraction effects from the origin, characteristic in an infinite angular co-ordinate space, are also deleted from the partial Green's function. The initial contour integral is then manipulated to yield alternative representations suitable for calculation of the transmission properties of the slab, and also of its guiding properties in terms of trapped and leaky modes. By use of high-frequency asymptotic approximations in the integrand, one may apply the saddle point method for evaluation. The integrand can be decomposed so as to yield a rich variety of individual ray-optical fields that include either all of the ray fields with multiple reflections on the inner boundary and inside the layer, or some suitably selected ray fields, with collective treatment of the remainder. For certain combinations in the latter instance, the remainder can be expressed in terms of a single ray field weighted by a composite slab transmission coefficient that contains corrections, due to curvature, of the transmission coefficient for a planar slab. The trapped and leaky mode contributions, when relevant are also included in this treatment. Various cases are discussed to illustrate the versatility of the asymptotic procedure.

ANALYSIS AND APPLICATIONS OF ACTIVE MICROWAVE REFLECTORS

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Naval Postgraduate School
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The first part of this investigation deals with the numerical behavior of a conducting wire of arbitrary dimensions loaded by one or more active elements along the length and illuminated by a plane electromagnetic wave of arbitrary polarization and direction of incidence. Sample results for the radar cross-section and scattering pattern are presented for a scattering wire, while the gain, radiation pattern, signal-to-noise ratio and effective aperture are presented for transmitting and receiving wires. The significant control in the behavior of a passive wire when loaded with one or more field effect transistors operating in the negative resistance mode at or near optimum conditions is illustrated and extended to multiple wires in random or standard array configurations employing straight or bent conducting wires.

The second part of this investigation deals with a wide variety of potential applications of the proposed technique and particularly for maximally absorbing or reflecting chaff, reflector antenna surfaces formed from closely-spaced active wires (e.g. horns, corner, parabolic and flat plate reflectors), loop, dipole and yagi antennas, inflatable jammers, active waveguide terminations, microwave cavities, anechoic chambers, shielded rooms and shielding nets as well as other microwave and electronic warfare applications.

A NOVEL MICROSTRIP ANTENNA FEED FOR A PARABOLOIDAL REFLECTOR WITH SIMULTANEOUS RCP AND LCP POLARIZATION

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A novel microstrip antenna feed has been developed for a paraboloidal reflector which provides simultaneous right circular and left circular polarization and low sidelobe levels over moderate bandwidths. This arrangement obviates the need for the usual waveguide orthomode transducer and thus decreases the weight of the feed. The basic feed element is a square patch $.55\lambda x.55\lambda$ fed at two orthogonally situated coaxial feed points inset 0.11 λ from the edge, as described by Millar and Carver [Proceedings 1980 University of Illinois Allerton Antennas Application Symposium]. In order to obtain low sidelobe levels, the square patch is placed at the base of a small conical feed horn with a flare angle of 36°, a base diameter of 1.10 λ, and a mouth diameter of 1.68 λ. This arrangement produced a feed pattern which was approximately 28 dB down at the angle subtending the dish edge. The first sidelobe of the feed pattern was at -28 dB and the half-power beamwidth of the feed pattern was 44°. The on-axis axial ratio was typically 2 dB on the beam peak.

In order to obtain enhanced bandwidth from the normally high-Q microstrip patch element, the substrate thickness was increased to approximately 0.25" by using a composite of 0.25" Hexcell honeycomb panel laminated to 0.00625" copper-foiled PTFE used on both sides of the Hexcell. One of the thin PTFE sheets was used as the ground plane and the other thin sheet was etched so as to leave a single square patch on one side. An Anaren Model 10040-3 hybrid coupler was bonded to the reverse side of the patch/horn feed so as to produce the necessary phase quadrature conditions for both senses of circular polarization.

A version of the above design was constructed to operate over the 2200-2300 MHz band. The VSWR over this bandwidth did not exceed 1.30 and the center-frequency VSWR was 1.12. With a 4' diameter reflector, the secondary pattern had a beamwidth of 7.8°, and a sidelobe level of -30 dB. The on-axis axial ratio was 2 dB for both senses of circular polarization.

ON BORESIGHT ERROR COMPUTATION BY SURFACE INTEGRATION

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In this paper we present a modified surface integration method for the numerical analysis of radome electromagnetic effects. The method eliminates numerical errors which arise from wide angle beam antennas in small radomes.

The Kirchhoff integrals give the field at any point in space from a knowledge of its value on a closed surface. On carrying out the integration over the surface of the radome, one has to assume a discontinuity in the surface field as it passes from a finite value to zero. This results in further assumptions like peripheral currents and charge build up. When the radome is rotated in the antenna coordinate system, the integration surface and the additional charges vary since they are functions of the angle of rotation. This results in numerical errors which depend on the angle of rotation. It has been found that these errors can be of the same order of magnitude as the B.S.E. resulting from transmission distortion for some antenna-radome systems. We have succeeded in eliminating the former source of error by designing a modified surface over which the integration is performed. This modified surface is constructed from that part of the radome protruding from a circular or square plate, fixed in the antenna coordinate system, and the exposed part of the plate. It can easily be shown that for an air radome the result of integrating over this modified surface is independent of the angle of rotation of the antenna. Furthermore, for symmetrical beam antenna patterns, the modified integration over an air radome gives a zero B.S.E., as expected.

In this work the antenna aperture is divided into sub apertures. The advantage of this approach is that the field incident on the flat sheet can, justifiably, be taken as a plane wave since the radome is in the far field of each sub aperture. In contrast, in other approaches the near field is calculated first on the inner side of the radome and the plane wave approximation is assumed for the near field of the antenna. We point out that our approach does not require any considerable increase in computer time since the transmission coefficients for a flat sheet are given to a good approximation by polynomials of low degree.

Good agreement was obtained between calculated and measured B.S.E. for a variety of antenna-radome systems.

SESSION B-11 ANTENNAS II: ARRAYS AND RADIATING ELEMENTS
FRIDAY 8:30 - 12:00
SANTA BARBARA, Room A

Chairman: C. M. Butler
University of Mississippi
University, MS

ANALYSIS OF A SLOT RADIATOR
IN A DIELECTRIC-COVERED
PARALLEL-PLATE WAVEGUIDE

R.D. Nevels, Electrical Engr. Dept., Texas A&M University, College Station, Texas.
C.M. Butler, Electrical Engr. Dept., University of Mississippi, University, Mississippi.

The transmission of electromagnetic energy through the broadside of a waveguide is an important problem in aperture antenna theory. Often a radome in the form of a dielectric slab is placed over the open aperture. While the dielectric slab provides interior environmental protection for the waveguide, the addition of the slab tends to alter the radiation pattern of the waveguide aperture. A change in the far field radiation pattern of the waveguide aperture is due mainly to changes in the amount of energy which is transmitted through the aperture and to the production of surface waves in the dielectric slab.

In this paper we present an integral equation approach to the analysis of a dielectric-covered parallel-plate waveguide with a slot in one plate (see Figure 1.). The waveguide is excited by an interior TEM wave. The parallel plates are assumed to be vanishing thin perfect conductors. It is assumed that the dielectric loss is small in the region of the parallel plates, in the dielectric slab and in the region above the slab. An integral equation is formulated in terms of the unknown tangential electric field in the slot and is solved numerically for several cases of interest. Far fields above the dielectric slab and scattering parameters inside the parallel plate guide are calculated using the numerically determined slot electric field.

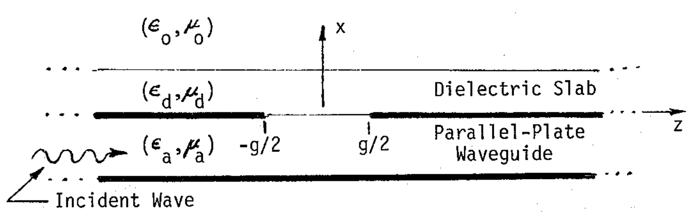

Figure 1. Parallel plate waveguide covered by a dielectric slab and having a slot in one plate.

RADIATION CHARACTERISTICS OF SLOT ANTENNA ON LARGE BODY-OF-REVOLUTION

Te-Kao Wu
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Slot antenna is often used in flying vehicles, since it can be installed conformally in the skin of the vehicles. But the radiation pattern of the slot antenna may be seriously altered by the near-by conducting edges or surfaces. It is therefore important to evaluate the effect of the slot antenna position on its radiation patterns.

In this paper the vehicle is modelled by a finitely conducting body-of revolution (B.O.R.), as shown in the figure, where δ is the thickness of the vehicle skin, σ is the conductivity of the skin metal. The slot antenna is next modelled by an infinitesmal and circumferential gap in the vehicle skin and uniformly excited with 1 volt across it. To find the slot antenna's radiation pattern, the same integral eqation methods as were used before (Mautz and Harrington, Appl. Sci. Res., 20, 405-435, 1969, or Wu and Tsai, Rad. Sci., 12, 709-718, 1977) are used to calculate the unknown surface currents induced on the vehicle's skin. The radiation pattern are then calculated from these surface currents. Radiation patterns are obtained for three different slot position on a large B.O.R. with $a=5\lambda$, $h=7\lambda$ and suface impedance of 100 or 1000 ohms. The effects of the slot position on its radiation pattern and the versatility of this analytical method will be discussed as well.

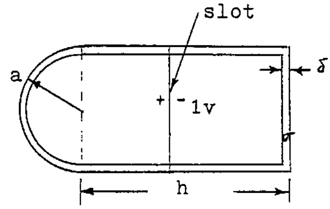

Figure 1. Geometry of a B.O.R. model consisting of a cylinder and a hemisphere.

EFFECT OF ARRAY SIZE AND SHAPE ON ELEMENT PATTERNS

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This paper describes modifications in the characteristic radiation pattern of a dipole element in the environment of a regular array of terminated dipoles as the size and shape of the array is varied. In particular, the approach to known limiting forms for an infinite planar array and an infinite linear array (P.W. Hannan, IEEE Trans. AP 12, 423-433, 1964; W. Wasylkiwskyj and W.K. Kahn, IEEE Trans. AP 25, 597-604, 1977), as well as the transition between these two extremes are examined.

Array performance is readily understood in terms of the pattern radiated when one port of the array is excited and all others terminated. In small arrays these are functions of the particular kind of antenna element employed and of the position of the excited port in the array. However, the element patterns become essentially the same for interior elements of large arrays. Furthermore the possible limiting or optimum patterns obtained when the array is fed through an interconnecting impedance matching network are drastically constrained.

Some of these features were discussed previously in the essentially 2-dimensional context of a planar array of line sources (W.K. Kahn, IEEE Trans. AP 25, 747-755, 1977). This paper presents the 3-dimensional case.

SIDELOBE CONTROL IN PARTIALLY EXCITED CYLINDRICAL ARRAYS*

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Traditional analytical approaches to the synthesis of low sidelobe patterns for cylindrical arrays are inherently difficult because the element pattern cannot be factored out of the pattern expression, and also because the latter cannot be expressed as a polynomial or other simple form. Thus there are no extensive libraries of pattern/illumination sets for cylindrical arrays as there are for linear arrays. However, the pattern synthesis in this case may be approached as a system optimization process already widely used in other fields (S. P. Applebaum, "Adaptive Arrays," Trans. IEEE, AP-24, No. 5 (1976)). The authors have successfully used this method, adopting as criterion the maximization of the desired received signal from an on-axis source with respect to noise power from jammers uniformly spaced about the array except for a narrow window centered on the source. Jammer noise power is expressed in terms of the assigned element weights and a covariance matrix of the signals from the jammers. The optimum set of weights is the matrix product of the inverted covariance matrix and a column vector of the complex conjugates of the desired unweighted signals from the source. The process produces very low sidelobe symmetric patterns with controllable beam widths and sidelobe tapers. This is achieved through control of window width and tapering the jammer noise power. The process is used also to obtain optimum antisymmetric patterns, essentially by minimization of the on-axis boresight error caused by jammer noise power. The result is optimum antisymmetric patterns with features which are also controllable through window-width and noise-power tapering.

We conclude that provided the complex element pattern in the array environment is known, it is a relatively simple matter to compute optimum excitations for symmetric and antisymmetric patterns. This procedure has been successfully utilized in the design of an electronically scanned cylindrical array.

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*This work was sponsored by the Defense Advanced Research Projects Agency and the Department of the Army under Air Force Contract F19628-80-C-0002 (ARPA Order 3391). The U.S. Government assumes no responsibility for the information presented.

Plane Wave Spectrum Analysis of Coupling Between a Pair of Near-Field Directive Antennas

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The Plane Wave Spectrum (PWS) Analysis technique [1-3] is used to analyze the electromagnetic coupling between a pair of directive antennas that are located within the radiating near-field of each other. The PWS antenna coupling integral has been implemented in an efficient computer algorithm. The computer model has been used to compute (near-field) mutual gain relative to a pair of isotropic radiators versus antenna orientation angles for a wide range of longitudinal and lateral separation distances [3]. Computed results are compared with measured results for two 4-foot paraboloidal dish antennas for two different near-field separation distances to demonstrate the validity of the PWS computer model.

1. D. M. Kerns, "Plane Wave Scattering Matrix Theory of Antennas and Antenna-Antenna Interaction: Formulation and Application," Journal of Research of the National Bureau of Standards, Vol. 80B, No. 1, pp. 5-51, January 1976.

2. C. E. Ryan, Jr., E. E. Weaver, and W. P. Cooke, "Development of Total Electromagnetic Effectiveness During Ship Design," Georgia Institute of Technology, Final Technical Report, Contract N00024-77-C-5338, December 1979.

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Mutual Impedance from Far Field Data

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Various theories for the computation of mutual coupling between antennas require the explicit knowledge of an antenna's pattern function for both real and imaginary values of argument. (e.g. Wasylkiwskyj, W. and Kahn, W., IEEE Trans., AP-18, 204-216, 1970.) The prospects for a numerical analytic continuation of the "visible" antenna pattern into the "invisible" regions about $\mathbb{R}$ are considered. Such continuations, being notoriously unstable, often require external auxiliary constraints to restore continuous data dependence. In this connection, we explore the use of the antenna measurable self-impedance and its relationship to the pattern. A "nearly-best-possible" method of numerical analytic continuation is introduced. (Miller, K. and Viano, G. J. Math. Phys., V. 14, #8, 1037-48, 1973.) Through numerical experiment, the sensitivity of "invisible" pattern reconstruction to data noise and accuracy is developed with the computation of various coupling integrals.

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MONOPOLE ANTENNAS ON LOSSY GROUND PLANES

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A moment method analysis of a monopole antenna mounted on a finite circular ground plane is described. This analysis is based upon a wire-grid model using filamentary wires. The ground plane wires are all radials, to take advantage of the structure's azimuthal symmetry. Current distribution results indicate large current ripples on the ground plane, a phenomenon which could be important in the design and use of these antennas. Analytic results compare well with available measurements and GTD computations.

The techniques used in the analysis of perfectly conducting structures are extended to include lossy ground planes. An "effective impedance", which can vary radially, is used to describe the losses analytically. Several parametric studies have been made of current distributions and radiation patterns as functions of changing ground plane size, losses, and loss distribution. The resulting data can be useful in the performance evaluation of monopoles on lossy surfaces.

RESONANCE AND Q PROPERTIES OF ISOSCELES TRIANGULAR PATCH ANTENNAS OF 60° and 90° VERTEX: Edward F. Kuester and David C.Chang, Electromagnetics Laboratory, Dept. of Electrical Engineering, University of Colorado, Boulder, CO 80309

The solution of the canonical problem of TEM wave reflection at an open-ended dielectric-loaded parallel-plate structure has previously been used to compute the resonance frequencies and Q of rectangular microstrip patch antennas, based on the transverse resonance concept. In the present paper, this idea is extended to the treatment of isosceles triangular patches with vertex angles of 60° and 90°. Comparison of Q and resonant frequency will be made with previously obtained results for rectangular patches, and the relative advantages of each type of patch will be discussed.

MICROSTRIP DIPOLES ON SPHERICAL STRUCTURES

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An elementary electric dipole tangent to the outer surface of a dielectric layer (substrate) which coats a metallic sphere is considered. The substrate is in turn covered by another dielectric layer with a higher refractive index, that is surrounded by free space. Exact expressions are obtained for the electromagnetic field produced by the dipole inside the coating layers and in free space, via an extension of the dyadic Green's function technique of Tai (1971). Asymptotic expansions are derived for a sphere whose diameter is large compared to the wavelength; in particular, the role of surface waves is discussed. These asymptotic results are compared to numerical results from the exact solution. Arrays of elementary dipoles are discussed in detail.

Tangential dipoles of finite length are considered next. A numerical procedure is developed for the determination of the current distribution and of the self-impedance of each dipole, and of the coupling between dipoles. These results are applied to the study of one- and two-dimensional arrays of (curved) dipoles.

SESSION B-12 MEDIA AND EARTH INTERACTION
FRIDAY 8:30 - 12:00
SAN GABRIEL, Room A

Chairman: G. Brown
Applied Science Associates, Inc.
Apex, NC

TRANSMITTER AND RECEIVER APERTURE AVERAGING EFFECTS FOR THE INTENSITY FLUCTUATIONS OF A BEAM WAVE IN THE TURBULENT ATMOSPHERE

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A simple, closed-form of intensity variance for a partially (spatially) coherent source with a finite aperture is developed. It is shown that the fluctuations of intensity for a partially coherent source in weak turbulence decreases when increasing the source size; opposite results are obtained for a coherent source. This form of intensity variance is also applied to calculate the receiver aperture averaging effect; it is shown that the fluctuations in the beam wave case do not monotonically decrease when increasing the receiver aperture such as in the plane wave case. The reason is that the fluctuations on the axis of the beam wave are smaller than the fluctuations off the axis. Extended Huygens-Fresnel principle with the approximation of quadratic structure functions for the source and the medium is used. Validity of our results in this approximation are discussed.

A COORDINATE-FREE APPROACH TO WAVE REFLECTION FROM A MOVING MEDIUM

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The object of this paper is to present a coordinate-free method in solving problem of wave reflection from the surface of a moving medium. Based on the direct manipulation of vectors, dyadics and their invariants, the method eliminates the use of coordinate systems. It facilitates solutions and provides results in a greater generality. The paper contains the following results in coordinate-free forms: (1) the constitutive relations of a moving medium, (2) the dispersion equation, (3) the direction of field vectors, (4) the phase, group and energy velocities, and (5) the transmission and reflection coefficient matrices.

SCATTERING FROM A RANDOM SLAB

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The one-dimensional wave propagation through an inhomogeneous slab is of considerable interest in various fields such as propagation in sea water, polar ice sheets, and ionosphere. In all these cases, the interest is in the reflected or transmitted amplitudes. The amplitude of the wave reflected from the slab, arrived at by the imbedding methods due to Bellman, et al (R. Bellman, R. Vasudevan and S. Ueno, J. of Math. Anal. & Applications, 44, 472-481, 1973), satisfies the Riccati equation and in an earlier investigation Sivaprasad, et al (K. Sivaprasad, R. Vasudevan and H. M. Hubey, Radio Sci. to be published, 1981), decomposed it into a non-linearly coupled set of iterative linear equations by taking into account the number of scatterings inside the medium. This order-of-reflection solution is used to investigate the problem of scattering from a slab which has random fluctuation in its dielectric constant. Using this method we obtain expressions for the average reflected power, the simplest one of which is identical with Ghandour's results (E. Ghandour, SIAM J. App. Math., 28, 885-898, 1975). A Fokker-Planck like equation for the joint probability density of the real and imaginary parts of the reflections function is also obtained from the order-of-reflection solutions (Sivaprasad et al. [1981]) using a technique for non-linear equations described by Van Kampen (N. G. Van Kampen, Physics Reports, 24, 171-228, 1976). Theses results are significantly different than those of Ryzhov (Y. A. Ryzhov, Radio Science, 11, 121-126, 1976), Papanicolau and Keller (G. C. Papanicolau and J. B. Keller, SIAM J. App. Math., 24, 287-305, 1971), and Ghandour (E. Ghandour, SIAM J. App. Math., 28, 885-898, 1975).

ATTENUATION CONSTANT OF COHERENT FIELD IN DENSE SPHERICAL PARTICLES

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Seattle, Washington 98195

The propagation constant of the coherent field in a random distribution of particles is usually given by a well known expression, sometimes called "Van de Hulst" formula. This formula is adequate for a tenuous distribution of particles. However, since the forward scattering amplitude for a plane wave incidence is used in this formula, it is generally not valid for a dense distribution. In the Van de Hulst formula, the attenuation constant which is the imaginary part of this propagation constant is equal to one half of the extinction coefficient. This paper presents a detailed experimental study of the attenuation constant in a dense medium, and the ratio of the actual attenuation constant to that of the Van de Hulst formula is given for various particle sizes and number densities. The study of the phase constant is not included here. The experiments are conducted using a HeNe laser (λ = 0.6328 μm) and Dow uniform latex particles with D = 0.109 μm and 11.9 μm. The volume densities range from 0.001 to 10% for D = 0.109 μm and 0.001 to 40% for D = 11.9 μm. The measured results of D = 0.109 μm show a sharp decrease of the attenuation constant for high densities; whereas, the results of D = 11.9 μm show a 10 to 20% increase of the attenuation constant for volume densities higher than 10%. Some theoretical solutions are compared with the experiments.

SCATTERING CROSS SECTIONS FOR COMPOSITE RANDOM SURFACES--
FULL WAVE ANALYSIS

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Solutions have been derived for the scattering cross sections per unit area of the rough surface using the full wave approach. For slightly rough surfaces the full wave solutions are shown to reduce to the perturbation solution. When the major contributions to the scattered fields come from the neighborhood of stationary phase (specular) points of the rough surface, the full wave solutions are shown to reduce to physical optics solutions. Since the results of the two general approaches to random rough scattering, perturbation and physical optics, are shown to be special cases of the full wave solutions, the limitations of these approaches can be precisely determined and the differences between them reconciled.

The principal motivations for this work are to extend the full wave analysis to composite rough surfaces with multiple roughness scales and to explicitly account for shadowing effects in the results. The main distinguishing feature of the individual rough surface h_i is its correlation distance l_i. However, no restrictions are made on the variance of the rough surface heights σ_{oi}. This work can therefore be applied to scattering by rough seas or by hilly terrain covered by tall trees.

The expressions derived for the scattering cross section, using the full wave approach, are presented. The familiar high frequency approximations are extended to cases in which the reference planes of incidence and scatter are not coplanar. A composite model of the rough surface with different roughness scales is analyzed using the full wave approach. A two scale model is first considered. Using this model, the full wave analysis is shown to account for both specular scatter and Bragg scattering. The analysis is extended to composite surfaces with N uncorrelated surface heights h_i, (i=1, 2, ...N). In general, it is shown that the scattering cross section for the composite rough surface is a weighted sum of the cross sections for the individual rough surfaces h_i. Shadowing effects are explicitly accounted for in the analysis.

BISTATIC SCATTERING FROM A LOSSY, RANDOM, COMPOSITE SURFACE

G. S. Brown, Applied Science Associates, Inc., 105 E. Chatham St., Apex, N. C. 27502

In a previous paper [G. S. Brown, IEEE Trans. Ant. & Propg., AP-26, 472-482, 1978] an asymptotic model for backscattering from a perfectly conducting random surface having many scales of roughness was developed based upon rigorous perturbation theory [M. L. Burrows, Can. J. Phys, 45, 1729-43, 1967]. In this paper it is shown how this formulation can be extended to the case of bistatic scattering from a lossy, dielectric, random surface characterized by many scales of roughness, i.e. a so-called composite surface. All the essential elements of the earlier analysis are basically unchanged with the exception that the polarization dependent (and now dielectric dependent also) factor Γ_{pp}, becomes more complicated. The key to the extension is the determination of the field discontinuities across the large scale or unperturbed surface. Since the large scale part of the surface is assumed to be very gently undulating, the field discontinuities can be estimated using the tangent plane approximation. The approach yields not only the like-polarized component of the scattered field but also the cross-polarized component. Numerical comparisons with the tilted plane α_{pp}, polarization dependent coefficients are presented and some differences are noted. The results developed here are shown to yield a cross-polarized backscattered power that is very similar in character to the results provided by second order small scale perturbation theory [G. R. Valenzuela, IEEE Trans. Ant. & Propg., AP-15, 552-557, 1967]. Of particular importance is the fact that the dielectric nature of the surface has no essential impact on the spectral partitioning required in the asymptotic model. That is, the transition between the dominance of the zeroth and first order perturbation field terms is not impacted by the dielectric character of the surface.

AN IMPROVED MODEL FOR SCATTERING FROM ROUGH TERRAIN

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Theoretical models that include a number of physical phenomena have been developed to describe very accurately electromagnetic wave scattering from rough terrain. For comparison with experiment, a site has been selected at which L-band scattering data exist. The original agreement was encouraging. In this paper we will discuss two significant, new aspects which have been added to the formulation, resulting in an improved comparison. These are: inclusion of azimuthal variation in power pattern and scattering cross section, σ_0; and an extended glistening surface area.

The theoretical expressions for calculating the specular and diffuse scattering from rough surfaces include parameters related to the local terrain features. These values are obtained by applying statistical estimation techniques to digitized terrain maps. The maps have been divided into rectangular cells, considered to be homogeneous and isotropic. Each cell is characterized by a mean height, variance, degree of correlation, statistical height distribution, and an appropriate dielectric constant. The model includes spatial inhomogeneities from cell to cell, multiple specular reflection points, global and local shadowing with explicit shadowing functions for Gaussian and exponentially distributed surface heights. The antenna power patterns of both transmitter and monopulse receiver are in the model and signal processing losses can be included.

There are some interesting aspects to the comparisons. Surface roughness causes attenuation of the specularly reflected rays. To account for this attenuation, cells surrounding the successive specular points are further subdivided and variances in surface height of the smaller regions are used in the calculation. Excellent agreement has been obtained with the experimental coherent sum signal. As part of the study of diffuse multipath, analytical and computer studies have shown that, for some parameter ranges, the classical definition of the glistening surface as given by Beckmann and Spizzichino is not sufficient. (The classical definition does not take into account the angular dependence of the scattering matrix in the expression for σ_0). In the present case, the actual contributing glistening surface is much longer and wider. This can result in a two order of magnitude increase in the diffusely scattered power. When this larger glistening surface, signal processing losses, and the azimuthal variation in σ_0 are included in the calculation, very good agreement is obtained for the error in antenna boresight pointing accuracy.

A DUAL APPROACH FOR WAVE PACKETS AND SOLITARY WAVES IN NONLINEAR SYSTEMS

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On leave of absence from the Dept. of EE, Ben Gurion
University of the Negev, Beer Sheva, Israel.

Recently (to appear in the Physical Review A: Math. and Gen., 1981) the duality of wave packets and localized pulses has been studied for linear systems. Presently the new concepts are examined for the case of nonlinear systems, using a ray tracing technique developed by the author (e.g., see "Nonlinear wave mechanics and particulate self focusing", Foundations of Physics, 10, 555, 1980). Harmonic generation and self focusing are the most prominent characteristics of nonlinear wave propagation. Their dual concepts are now considered. The dual of harmonic generation is the production of trains of coherent solitary waves, while the focusing or defocusing of the dual rays in spectral space describes the effect of nonlinearity on the spectral structure of these waves. It is shown, by means of an example, that the defocusing is an important factor in maintaining the stability of the solitary waves.

MAGNETIC FIELD ANALYSIS OF AN INFINITE LINE CURRENT OVER A PLANE LAYERED EARTH

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R3T 2N2

This paper will present the magnetic field perturbation of an infinite line current model due to the ground. The exact integral form for a homogeneous earth now yields a closed form solution in terms of well known mathematical functions and currently are being evaluated to a high degree of accuracy ($\varepsilon = 10^{-9}$). The previously accepted approximations for the case of stratified media have been incorporated, in order to generate the analytical expressions of the magnetic field components for the layered earth. Their numerical evaluation shows sufficient sensitivity of the perturbation to the main parameters, magnitude of the current source, its frequency, as well as the conductivities and their relative depth from the surface of the earth.

A complete understanding of this analysis is imperative for the inverse problems of identifying the level of the solar magnetic storms and their induction in the power transmission lines. It is also essential in deep electromagnetic sounding techniques to carry out geophysical explorations, which are two currently active projects at the University of Manitoba campus.

Results are compared with those of known computer programs, such as the one entitled EMFIN, that has been prepared by Anderson (Ben K. Sternberg, Wisconsin Report No. 77-1 May, 1977, Section B1 through B10, Madison, Wis. 53706) and is based on the solution of a horizontal electric dipole (J.R. Wait, IEEE Trans. on Antennas and Propagation, Vol. AP-14, No. 6, p. 790, 1966). Evidences for the validity of the two-dimensional model and its applicability to data inversion will be given, where an adequate simulation of the earth is used to fit the observed parallel and the normal components of the magnetic field on the surface of the earth.

SESSION F- 1 ATMOSPHERIC ATTENUATION, SCATTERING, AND ABSORPTION
TUESDAY 8:30-12:00 - June 16
SAN GABRIEL, Room A

Chairman: Richard T. Woo
Jet Propulsion Laboratory
Pasadena, CA

1\. Attenuation and Depolarization Over an Earth-Space Path at 12GHz: Measurement Results For Path Elevation Angles of 27 and 9 Degrees Using the CTS Satellite

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ABSTRACT

Attenuation and depolarization, primarily due to rain, has been measured at Crawford Hill, Holmdel, New Jersey, using the 12GHz beacon from the Communications Technology Satellite (CTS). Data recorded for a 3½ year period provided year-to-year comparison of attenuation and a large data base to provide attenuation-depolarization relationships. A few months of data were obtained at a path elevation angle of 9 degrees before the beacon signal was lost. These low angle data, although very limited, appear to show greater attenuation for a given rain rate than the higher angle data. The measured depolarization over both paths showed a decrease with increasing copolarized rain attenuation and lower path elevation angle. At an attenuation of 10 dB and elevation angle of 27 degrees, a median depolarization level of -15 dB was measured. This decreased to -13 dB for the same attenuation at the 9 degree elevation angle.

The measured attenuation and depolarization data were compared to results calculated from existing propogation models based on rain and were found to agree quite well.

2. MEASURED BOUNDS ON RAIN-SCATTER COUPLING BETWEEN SPACE-EARTH RADIO PATHS

D. C. Cox, H. W. Arnold and H. H. Hoffman
Bell Laboratories
Crawford Hill Laboratory
Holmdel, NJ 07733

A potential source of co-channel interference in satellite communication systems is rain-scatter coupling into a satellite-earth radio path from an adjacent communication satellite. In clear air, the interference level from a nearby satellite is determined by the sidelobe response of the earth-station antenna. During heavy rain, however, scatter from raindrops could produce additional coupling between the paths.

This paper presents results of rain-scatter measurements at 19 and 28 GHz for two space-earth paths separated by 0.85 degrees. No evidence of rain-scatter coupling was found at the levels limited by the antenna sidelobes. For rain attenuation up to 15 dB, measured upper bounds on coupling were -40 dB at 19 GHz and -45 dB at 28 GHz. The sidelobe-limited bounds were degraded by off-path-receiver noise for greater attenuations. These experimental bounds are consistent with theoretical predictions that scattered signal levels should be below the measurement threshold of this experiment.

3.

FADE DURATION AND INTERFADE INTERVAL STATISTICS MEASURED ON A 19 GHz EARTH-SPACE PATH

H. W. Arnold, D. C. Cox, H. H. Hoffman
Bell Laboratories
Crawford Hill Laboratory
Holmdel, NJ 07733

The temporal distribution of rain-produced attenuation has a significant effect on the performance of satellite communications systems operating above 10 GHz. This paper presents distributions and other statistics of fade durations and interfade intervals measured on a 19 GHz earth-space path with an 18.5° elevation angle. Observations spanned 2 years, and were reduced from chart recordings with 0.5 minute time quantization.

Median fade durations ranged from 7.5 minutes for 5-dB fades to 5 minutes for 40-dB fades. 5-dB fades occurred at an average rate of 185/year; this rate decreased to 11.5/year for 40-dB fades. Higher-attenuation fades were more isolated. 80% of the 40-dB fades were separated by more than 2 hours; only 35% of the 5-dB fades were separated by more than 2 hours.

Distributions were accumulated separately for the period of July and August. These months were shown previously to have the highest accumulations of severe (> 20 dB) attenuation. During July and August 5-dB fades occurred at a rate twice that for the remaining 10 months. Fades of 40 dB were 8 times more frequent during July and August.

4

A SITE DIVERSITY EXPERIMENT USING THE SIRIO SPACECRAFT

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Electrical Engineering Department
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

VPI&SU has two dual polarized receiving systems which continuously monitor the 11.6 GHz circularly polarized SIRIO spacecraft beacon. The receiving sites are spaced 7 km apart and view the satellite from an 11° elevation angle. Polarization isolation and attenuation values are recorded and stored in a central computer. These data are subsequently processed to yield single site and joint isolation and attenuation statistics. This paper describes the experiment and presents preliminary results.

TRANSMISSION AND BACKSCATTERING OF OPTICAL WAVES THROUGH FOG

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The transmission characteristics of optical waves through fog is important in communications, and the knowledge of backscattering from fog is useful in lidar studies. At optical wavelengths, considerable scattering takes place in fog, and therefore, the multiple scattering effects need to be taken into account for the study of these characteristics. This paper examines the multiple scattering effect in fog at optical wavelengths. An unpolarized plane wave is normally incident upon a plane parallel medium of fog. The forward and backward scattering intensities are calculated from the equation of transfer. The transmitted power and the backscattered power received by a receiver with different fields-of-view are calculated. The scattering characteristics of fog particles are calculated using the Mie solution and the actual fog size distribution observed at Point Loma under the assumption of spherical fog droplets. The results are obtained at wavelengths of 0.5 μ, 1 μ, 5 μ, 10 μ, and 15 μ with the receiver field-of-view of 1°, 10°, and 20°. The scattering characteristics at visible wavelengths, for example, 0.5 μ and 1 μ, are mostly in a forward direction and are peaked within 10°. Besides, the absorption effect is negligible at these wavelengths. However, the scattering characteristic becomes broader and the absorption becomes observable at 10 μ and 15 μ. For example, at 15 μ, the albedo is 0.343. The transmitted power received by a 10° field-of-view receiver varies from -21 dB to -157 dB, and the ratio of incoherent power to coherent power varies from -10 dB to +16 dB as the optical thickness increases from 5 to 40. However, the backscattered power is almost constant at -44 dB within this range of optical thickness.

6. SOME RESULTS OF HF RADIO NOISE MEASUREMENTS IN NIGERIA USING DIRECTIONAL ANTENNA

by

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ABSTRACT

In equitorial/tropical African countries such as Nigeria, most radio communications equipment designed and installed on predictions from extrapolated international data have consistently exhibited poor noise performance under local conditions. On the other hand, all the available international radio noise data such as the CCIR Report 322 relate to a short vertical receiving antenna. Although such an antenna may be suitable at very low frequencies, high-frequency long-distance communications requires, in practice, highly-directional antenna. Thus the need for establishing appropriate radio noise data cannot be overemphasized.

This paper will discuss the results of a two-year HF radio noise measurements in Nigeria using directional antenna with a view to establishing HF radio noise levels in the country, and to checking the noise predictions as reported in the CCIR Report 322. A simple measuring equipment having a high gain stability, low error value (± 1dB), wide dynamic range and relatively wide receiver noise bandwidth was used to determine radio noise in the frequency range of 1 - 30MHz during 1979 and 1980 on a continuous basis. Results obtained indicate, among other things:

(1) That, in general, severe radio noise is more frequent during the rainy season (April to September months) than during the dry or harmattan season (October to March months).

(2) That the expected highest radio noise levels do not necessarily occur in June, July and August as predicted by the CCIR Report 322 for the equitorial region but in August and September for the rainy season and November and December for the dry season.

(3) That the effect of antenna directivity is the increase of radio noise by an average of 9 - 11dB in the dry season and about 15dB in the rainy season above the values predicted by the CCIR Report 322 for short vertical antenna.

A major conclusion from the present work is that the effect of antenna directivity on radio noise levels is significant, and that expected months of severest radio noise levels for equitorial Africa do not necessarily obey the predictions of the CCIR Report 322.

7.

CROSSPOLARIZATION OF ICE PARTICLES AT 30 GHz

C. Yeh, Electrical Sciences and Engineering Department, University of California, Los Angeles, CA. 90024; R. Woo and J.W. Armstrong, Jet Propulsion Laboratory, California Institute of Technology, Pasadema, CA. 91103; and A. Ishimaru, Department of Electrical Engineering, University of Washington, Seattle, WA. 98195

Optimum design of modern satellite-earth communication system requires the knowledge of hydrometeor-induced differential attenuation, differential phase shift and crosspolarization factors. Due to higher transparency and higher eccentricity of ice crystals it has been suggested that the depolarizing effect of ice crystals may be even more significant than that of raindrops. This talk will present the results of our study on the scattering characteristics for ice disks (oblate spheroids) and ice needles (prolate spheroids) for sizes ranging from 0.25 mm to 2.5 mm at 30 GHz. Comparison will be made with Pruppacher-Pitter raindrops results. Our calculations are based on the extended boundary condition technique.

This paper presents the results of one phase of research carried out at JPL under contract NAS7-100 sponsored by NASA.

8.

MICROWAVE DEPOLARIZATION AND RAINDROP CANTING ANGLES

R.S. Butler, Communications Research Centre, Department of Communications, Ottawa, Ontario K2H 8S2 Canada

The depolarization of linearly-polarized microwaves propagating through rain has been measured in a dual-frequency experiment at 11 GHz and 17 GHz. Analysis of the data using the general theory of Oguchi, as approximated by Nowland et al. (Electron. Lett., 13, 676-678, 27 October 1977), leads to consistent values of the mean equivalent canting angle of the raindrops along the path. A strong correlation is observed between the canting angle and the attenuation within individual rain events and from one event to another, with smaller canting angles occurring at larger attenuations.

This paper presents conditional distributions of canting angles at various attenuation levels. A modification of the linear equiprobability relation between cross-polarization discrimination and the logarithm of attenuation is then proposed which includes the attenuation dependence of the canting angle. This approach may allow more reliable estimates to be made of microwave depolarization than are currently available.

9.

EARTH-SPACE RAIN ATTENUATION MEASUREMENTS AT 13 GHZ FOR SEVERAL SITES IN CANADA

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To obtain rain attenuation statistics for earth-space paths, the sky-noise temperature at 13 GHz was measured by radiometers installed at several locations across Canada. The sites were chosen to represent the Atlantic and Pacific maritime climates and various continental climates. Each radiometer antenna was directed toward an imaginary geostationary satellite at 114°W longitude. Data were recorded nearly continuously on digital magnetic tape at each location over a four-year period. These data have been analyzed to obtain annual, monthly and diurnal distributions of precipitation attenuation and fade duration.

The characteristics of these statistics peculiar to each climatic region will be identified and compared with the relevant meteorological data.

SESSION F-2 REFRACTION EFFECTS
TUESDAY 1:30 - 5:00
SAN GABRIEL, Room A

Chairman: Cullen Crain
Rand Corp.
Santa Monica, CA

A SIMPLIFIED MODEL FOR INTERPRETING THE DOPPLER SPECTRUM OF FORWARD SCATTER RADAR SIGNALS

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Department of Electrical Engineering and
The Engineering Research Institute
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High power, sensitive, doppler radar systems have proven to be very useful as electromagnetic probes to determine the dynamic state of the earth's atmosphere. There is great interest in measurements of this type because the resulting atmospheric models have direct application to current problems such as communication link design, weather forecasting and the dispersal of gaseous pollutants.

One of the radar systems which has demonstrated considerable potential for measuring parameters that are useful in characterizing the structure of the troposphere is the forward scatter CW doppler radar with a rake receiver. The advantages of this system are twofold; first, the signals reflected from the atmospheric structure are much stronger in the forward scatter case; and second, the rake receiver system effectively splits the atmosphere into horizontal time delay shells. For the 940 MHz system operating between Moingona, IA and Arlington, WI, a 10 MHz modulation rate results in time delay shell thicknesses ranging from 650 m at 2.5 km above the earth's surface to 150 m at a height of 12 km. The purpose of this paper is to describe the development of relatively simple model for use in interpreting the doppler spectrum of the signals emanating from a given time delay shell. The model is a combination of the "reflection by layers" model and the "anisotropic turbulence" model. The composite model is a Gaussian-shaped approximation to the anisotropic scattering power spectrum function. The process relates the anisotropy of the atmospheric turbulence to the half-power width of the equivalent Gaussian distribution.

The combination of the Gaussian-shapped scattering model plus the assummed Gaussian-shaped antenna patterns results in an expression for received power which is also Gaussian shaped and can be interpreted as the doppler frequency distribution function of the received signal. The half-power width of the composite doppler distribution function is related in a straight-forward way to the half-power widths of the equivalent scattering function and the antenna patterns. Since the antenna patterns are known, knowledge of the received signal doppler distribution function allows one to estimate the parameters of the equivalent scattering function. This, in turn, leads to estimates of the parameters of the anisotropic scattering model.

The model described in the preceeding paragraphs was used in interpreting data taken on the 940 MHz forward scatter radar system. The results of these interpretations are presented and discussed.

A STUDY OF TROPOSCATTER SIGNAL BEHAVIOUR

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Troposcatter communication links provide a reliable means of point-to-point communication. Whereas many such links exist in the developed countries, the development of troposcatter links in India is in the initial stages. An experimental 2.1 GHz CW link over a distance of 330 km, the first such link in India, was set up between Kanpur and Nainital to study the signal behaviour. This paper reports the results of the analysis of the data collected on this link and its comparison with simulated data.

Three types of investigation were carried out. Firstly, statistical parameters of the signal such as median level, depth of fading, and fade durations were obtained as a function of the time of day and season of the year. The strong influence of the monsoon was clearly evident. The signal was found to be weakest in summer. The strongest signal far exceeded the predictions based on conventional prediction methods such as the NBS method. It is felt that reflections from facets and occasional ducting are the cause of this. Secondly, signal strength was correlated with such meteorological parameters as the refractive index and its gradient at the surface and at various heights. For this purpose data was collected from the Indian Meteorological Department for the relevant times and locations. This study was aimed towards establishing the meteorological parameters which can be used for best predictions of path loss in the Indian sub-continent. Thirdly, theoretical models were used to simulate troposcatter signal. Comparison of such simulated signals with those observed on the link was carried out to estimate such parameters as the wind velocity, heights of scattering layers and their thicknesses, anisotropy of the scatterers, and the spectral index of refractivity fluctuations.

IMPROVING KNOWLEDGE OF MULTIPATH FADING

Luigi F. Mojoli - Telettra SpA

Abstract

Digital hops and long analog require a deeper knowledge of multipath fading. This paper supplies a model very close to experiments, simple and useful both for designing radio links and for analyzing hop performances.
Rules are given for the evaluation of the four parameters of the model; they are: multipath activity duration, depression of the median field during multipath, mean and standard deviation of fading in absence of multipath.
Usual rules underestimate both 50% and 20% fadings for hops longer than approx 150 Km.
A 360 Km hop over the Red Sea, conversely, is perfectly described by the model.
The knowledge of multipath activity duration provides a powerful tool for predicting the unavailability of digital radio links: unavailability by selective fadings is proportional to it and to a function of symbol rate multiplied by average echos' delay.

Luigi F. Mojoli - Telettra SpA, via Trento 30, 20059 VIMERCATE (Mi) Italy

A TECHNIQUE FOR OBTAINING TROPOSPHERIC REFRACTIVE RANGE ERROR CORRECTIONS FROM ANGLE ERROR MEASUREMENTS

E. E. Altshuler and K. Mano

Rome Air Development Center
Electromagnetic Sciences Division
Hanscom AFB, Massachusetts 01731

The performance of radar and navigation systems that operate at very low elevation angles is often limited by tropospheric refraction, which produces two main effects on radio waves, angular bending and range error. Accurate angle error corrections can be obtained by utilizing targets of opportunity, such as the limb of the sun, radio sources or satellites, the angular positions of which are precisely known. Radio sources, on the other hand cannot be used for range calibration and since the ranges of most satellites are not known to a sufficient accuracy, the range error correction still presents a problem. A method for obtaining an improved range error correction by utilizing measured angle error data for the same ray path is developed. An expression for the refractive angle error correction for a target based on the measured angle error of the calibration source is first derived; also the angular refraction is expressed as a function of the angle error. It is then shown that the range error correction for a target can be expressed as a function of the angular refraction and can be calculated from a set of angle error measurements, thereby providing an improved correction. Finally, the parameters and numerical methods which limit the ultimate accuracy of this technique are reviewed. In the formulation of this problem a time dependent spherically stratified non-ionized atmosphere with a monotonically decreasing index of refraction with altitude is adopted, so the solution is only valid at frequencies above which ionospheric effects are negligible and for atmospheres which do not have inversion layers in refractivity. Also, it is assumed that both the calibration source and target are above the troposphere.

ON THE MAXWELL-EQUATION BASIS FOR RADIATIVE TRANSPORT THEORY

Ronald L. Fante
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Wilmington, MA 01887

We have studied the relationship between Maxwells equations and radiative transport theory for the case of propagation in arbitrary non-dispersive random media. For monochromatic signals it is found that the specific intensity of radiation, $I(\underline{r}, \underline{s})$, at position $\underline{r}$ and in the direction $\underline{s}$ is related to the electric and magnetic fields, $\underline{E}(\underline{r})$ and $\underline{H}(\underline{r})$ via

$$I(\underline{r}, \underline{s}) = \frac{v}{2}\int_0^\infty k^2 dk e^{ik\underline{s}\cdot\underline{r}} \left\langle \mu \underline{h}(\underline{k}) \cdot \underline{H}(\underline{r}) + \epsilon \frac{k^2}{k_o^2} \underline{e}_{\perp}(\underline{k}) \cdot \underline{E}^*(\underline{r}) \right\rangle \quad (1)$$

where $\langle \; \rangle$ denotes an ensemble average, $\underline{e}(\underline{k})$ and $\underline{h}(\underline{k})$ are the spatial Fourier transforms of $\underline{E}(\underline{r})$ and $\underline{H}(\underline{r})$, $\underline{e}_{\perp}(\underline{k})$ is the component of $\underline{e}(\underline{k})$ which is transverse to $\underline{k}$, μ and ϵ are the background permeability and permittivity, $k_o = \omega/v$, ω = radian frequency and $v = (\mu\epsilon)^{-\frac{1}{2}}$. When I is given by (1) it will be shown that it satisfies the radiative transport equation and the other postulates of radiative transport theory provided:

1) $\langle \underline{e}(\underline{k}) \cdot \underline{e}^*(\underline{k}') \rangle$ is sharply peaked about $\underline{k}=\underline{k}'$
2) $\langle \underline{e}(\underline{k}) \cdot \underline{e}^*(\underline{k}') \rangle$ is sharply peaked about $|\underline{k}| = |\underline{k}'| = k_o$
3) $\underline{e}(\underline{k})$ is approximately transverse to $\underline{k}$

The aforementioned conditions translate into restrictions on the nature of the fields and on the properties of the random medium. In particular they require that the fields be either quasi-homogeneous or highly directional, and that the random medium have permittivity fluctuations with magnitudes and correlation length which satisfy certain restrictions.

It will also be demonstrated that conditions (1)-(3) are sufficient for the specific intensity and the field mutual coherence function to be related via an angular Fourier transform.

ANALYTIC SOLUTION FOR THE TWO-FREQUENCY MUTUAL COHERENCE FUNCTION FOR SPHERICAL WAVE PROPAGATION

Dennis L. Knepp
MISSION RESEARCH CORPORATION
735 State Street, P.O. Drawer 719
Santa Barbara, CA 93102

The quadratic approximation for the phase structure function is used to obtain the two-frequency mutual coherence function $\Gamma(\Delta\rho,\Delta\omega)$ for spherical wave propagation through a finite slab with transmitter and receiver located in free-space on opposite sides of the slab. General analytic solutions are derived for two cases. In the first case the random slab is represented by a one-dimensional power spectrum of electron-density fluctuations corresponding to propagation through elongated irregularities as would occur for an equatorial satellite link to a ground station. In the second case the random slab consists of isotropic ionization irregularities.

Both cases taken together represent the extremes of the range of results to be expected for propagation through ionospheric fluctuations, solar wind irregularities or ionization irregularities caused by barium cloud instabilities.

For both cases the complex general analytic results are simplified by use of the thin phase-screen approximation (zero slab thickness) to obtain useful analytic expressions for $\Gamma(\Delta\rho,\Delta\omega)$ as well as the resulting impulse response function $G(\tau) = \int\Gamma(0,\Delta\omega)\exp(i\Delta\omega\tau)\,d\Delta\omega$. It is shown that the impulse response to an incident power delta function reduces to an exponential form in the strong scattering limit and to a Gaussian form in the weak scattering limit. The Gaussian form corresponds to pulse wander while the exponential form corresponds to dispersive spreading produced by multipath effects.

Using the thin-screen case as the starting point, the effects of the random medium thickness as well as variations in the transmitter and receiver locations are investigated and results presented for the impulse response function.

ON FIELD COMPUTATION IN RADIO FREQUENCY INTERFEROMETRY

A.Mohsen
Faculty of Engineering,Eng. Math.&Phys. Dept.
Cairo University,Giza,Egypt

In radio frequency interferometry,investigation of the EM field vectors is used to explore various geological features.These vectors may,in general,be represented in terms of two scalars.When a problem admits more than one representation,the relative convergence or usefulness of a particular representation for the derivation of asymptotic behaviors or for numerical treatment are discussed. When the probe is placed above a flat layered earth,the solution may be written in terms of Sommerfeld integrals.whose analytical solution is possible only for few cases.Various approximate techniques of different regions of validity may be employed.The numerical method can be used for arbitrary number of layers with general properties.Due to the considerable saving in computational time it provides,the FFT is a very promising method Various approximations and previous application of the FFT to these integrals are critically reviewed.The important role of the decomposition of the integrals on the region of validity and convergence of the FFT method is demonstrated.

CONVERGENCE CHARACTERISTICS OF GEOPHYSICAL TOMOGRAPHY USING ITERATIVE RAY TRACING

Roger D. Radcliff, Constantine A. Balanis, Herman W. Hill, Jr.
Department of Electrical Engineering
and
George E. Trapp, Jr.
Department of Statistics and Computer Science

West Virginia University
Morgantown, West Virginia 26506

Geophysical tomography is the process of mapping the electrical properties of the earth by transmission of electromagnetic waves between two boreholes on either side of the unknown structure. Traditionally, measurements of power transmitted along an assumed straight-line path through the anomaly are inverted to yield a spatial attenuation constant profile. This scheme works well for media in which refraction, reflection, and diffraction effects are not significant.

To extend geophysical tomography to media in which straight-line propagation is not a valid assumption, a method has been devised which involves an iterative sequence of ray tracing with reflection corrections and algebraic reconstruction (R.D. Radcliff and C.A. Balanis, IEEE Trans. Ant. Prop., March 1981). Ideally, the reconstructed profile will begin with the straight-line solution and converge to a stable and more accurate image. However, many factors influence this critical convergence behavior. This investigation examines the effects of scanning angle, anomaly size, contrasts in media parameters, and quality of the first estimate on the convergence characteristics of this new method. The transmission data is obtained by a full wave numerical scattering program, so that refraction, reflection, and diffraction contributions are included.

SESSION F-3 SENSING SURFACES
THURSDAY 8:30 - 12:00
SAN PEDRO ROOM

Chairman: E.K. Smith
Jet Propulsion Laboratory
Pasadena, CA

SURFACE-CURRENT SOLUTION FOR ROUGH-SURFACE SCATTERING

J. Carl Leader
McDonnell Douglas Research Laboratories
St. Louis, Missouri 63166

The properties of the electromagnetic field scattered by a rough surface can be described in terms of the induced current correlations on the rough surface in the manner proposed by Carter [J. Opt. Soc. Am. 70, 1067 (80)]. The current correlations can in turn be described by the integro-differential equations relating the current density to the tangential electric field (for a perfectly conducting surface). The tangential electric field distribution is related to the surface height distribution in a straightforward manner. It is demonstrated that if the surface Green's function admits an expansion in an angular spectrum of plane waves (Weyl's integral), the scattered-field intensity is simply related to the ensemble-averaged tangential field distribution. The TE predictions of this theory agree with physical optics results, while the TM predictions yield a polarization dependence similar to that of perturbation theory although the scattering integral is of the physical optics type.

REMOTE SENSING OF OCEAN SURFACE CURRENT AND CURRENT SHEAR BY MICROWAVE RADAR

Dale L. Schuler
Naval Research Laboratory
Washington, D.C. 20375

A dual-frequency microwave radar technique has been developed which is capable of measuring ocean surface currents and a vertical profile of current strengths to considerable depths.

The radar measures currents by monitoring the perturbations in wave phase velocity δCp caused by the presence of the current. The dual-frequency radar technique is capable of resonating (spatially) with an ocean wave system having wavelength λ_g

$$\lambda_g = C/(2\,\Delta f\ \cos\Psi) \tag{1}$$

where, C = speed of light, $\Delta f = f_2 - f_1$ the transmitted frequency difference and, ψ = the grazing angle. The phase velocity of this wave $Cp(\lambda_g)$ is well-known and deviations in Cp may be detected by monitoring the position of a dual-frequency resonance line in the Doppler spectrum of the radar output. The radar measures exponentially weighted values of the current to depths $d(=(4\Pi)^{-1}\lambda_g)$. The radar technique reported here utilized multiplexed values of Δf (100 values in 5ms) to make virtually simultaneous measurements of the current vs. depth d. Experimental measurements of the vertical current shear were carried out from the German North Sea Tower as part of the international MARSEN (Maritime Remote Sensing Experiment) program. The current profiles obtained through the radar measurements were compared with single-frequency radar measurements of currents at the surface and with conventional current meters placed at various depths below the surface. Inversion of the radar weighted current values to actual current profiles will be discussed.

POLARIZATION EFFECTS IN SCATTERING FROM BREAKING WAVES

Lewis B. Wetzel
Naval Research Laboratory, Washington, D.C.

Radar observations of breaking waves, particularly at low grazing angles and high resolutions, generally show a variety of interesting, and confusing, polarization effects: e.g. horizontally polarized returns are usually spikier than vertically polarized returns, but returns at the two polarizations look much the same at very low grazing angles. While there are at present no really convincing scattering models through which such effects can be understood, a recently proposed "plume" model shows promise (Wetzel, 1981 IUCRM Symposium on Wave Dynamics and Radio Probing of the Ocean Surface). In this paper we will compare the plume model with various other models often proposed for scattering by breaking waves (wedge, spray, Bragg models). It is found that the choice of model will depend upon the frequency of the radar, and that the plume model is most appropriate for the popular microwave frequencies between the S and Ku bands. Moreover, the plume model provides a reasonable basis for understanding many of the polarization effects observed at these frequencies in low-angle scattering from breaking waves.

EMISSION FROM AN IRREGULAR LAYER EMBEDDED WITH MIE SCATTERERS

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Remote Sensing Laboratory
University of Kansas
Lawrence, Kansas 66045

ABSTRACT

A theoretical model for microwave emission from an inhomogeneous layer characterized by Mie scatterers has been developed using the radiative transfer method. The top and bottom boundaries of the layer are assumed to be randomly rough surfaces and the scatter characteristics are assumed to be describable by the Kirchhoff scatter model. The effect of surface roughness and the difference between the Mie and the Rayleigh layer are illustrated. Some comparisons with emissions from a snow layer are shown. It is noted that the model is important for explaining emission from optically thin snow layers.

RADIATIVE TRANSFER THEORY FOR MICROWAVE REMOTE SENSING OF AN INHOMOGENEOUS MEDIUM WITH ROUGH SURFACES

R. T. Shin, S. L. Chuang, and J. A. Kong
Department of Electrical Engineering and Computer Science and Research Laboratory of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

In the active and passive microwave remote sensing of earth terrain, the scattering effects due to medium inhomogeneities and surface roughness play a dominant role. Two theoretical models have been developed to characterize terrain media. The volume scattering effects can be accounted for by modelling the earth terrain either as a random medium or as a homogeneous medium containing discrete scatterers. The rough surface effects are taken into account by modifying the boundary conditions for the intensities. The bistatic coefficients for a randomly rough surface obtained under the Kirchhoff approximation are used. The radiative transfer theory is then used to calculate the brightness temperatures for passive remote sensing and backscattering cross sections for active remote sensing. The radiative transfer equations are solved numerically using a Gaussian quadrature method and the results are illustrated by plotting the backscattering cross sections and the brightness temperatures as functions of observation angle, frequency and depth for different polarizations. The theoretical results are illustrated and compared with experimental data collected from a snow field.

RANDOM MEDIUM MODEL FOR MICROWAVE REMOTE SENSING OF EARTH TERRAIN

J. A. Kong, R. T. Shin, F. J. Vallese,
S. L. Chuang, and J. K. Lee
Department of Electrical Engineering and
Computer Science and Research Laboratory
of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

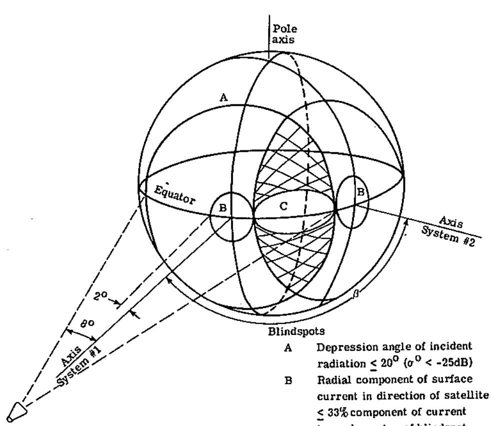
In the interpretation of microwave remote sensing data collected from radiometric and radar measurements of various earth terrains such as snow-ice and vegetation fields, the model of a random medium in the characterization of the volume scattering effect has proven to be very successful. The random medium model is characterized by a correlation function with the parameters of variance, correlation lengths, and mean of the permittivity. In applying the theoretical result to match experimental data, it is found that for snow-ice fields, the horizontal correlation length is no less than the vertical correlation length whereas for vegetation fields their relative size depends on the types of vegetation. The change in the imaginary part of the mean permittivity on the top surface of a snow field also enables us to interpret the diurnal changes. The random medium model can be used to interpret both the active and passive measurements, and this is demonstrated by matching combined active and passive data sets collected from a snow field. In order to show that the random medium model does characterize the terrain medium, a correlation function study is made on several snow and ice samples. It is found that the correlation functions are exponential in character and the correlation lengths correspond closely to the actual size of the ice particles in snow or air bubbles in ice. Also, the parameters for the random medium model obtained with the correlation functions study agree closely with the parameters used in the interpretation of experimentally measured data.

OCEAN SURFACE AREA COVERAGE BY SATELLITE-MOUNTED RADARS

R. E. McIntosh and R. S. Raghavan
Department of Electrical and Computer Engineering
University of Massachusetts, Amherst, MA 01003

The surface area of the ocean, which can be remotely sensed from a satellite platform, depends on the satellite's altitude and position. It also depends on the depression angle formed by the signal transmission path and the ocean surface in many cases of practical importance. For example, the reflection of radar signals by the ocean at mean depression angles less than 20^o results in scattering cross section areas smaller than -25 dB. Thus, only that area of ocean surface for which the depression angle exceeds 20^o might be considered as an area which can be remotely sensed.

In this paper, we solve expressions for the ocean surface area that can be remotely sensed by a single orbiting radar aimed towards the earth's center. We find that our solution is applicable to more complicated situations, such as that shown in the figure below. Here, the area of interest is that for which ocean surface currents might be detected using two separate Doppler radars in geostationary orbit. Our calculations show that large areas ($\approx 10^7$ km^2) of the earth's oceans can be remotely sensed by a two-radar system so that a vector map of the ocean surface current can be achieved.



Blindspots

A Depression angle of incident radiation $\leq 20^o$ ($\sigma^o < -25$dB)

B Radial component of surface current in direction of satellite $\leq$ 33% component of current towards center of blindspot

C Angle between components of current greater than 80^o

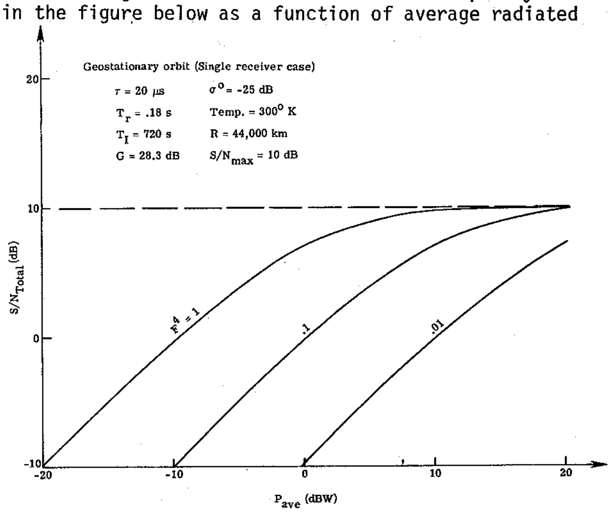
ANOTHER LOOK AT OCEAN SURFACE CURRENT MEASUREMENTS FROM SATELLITES

C. T. Swift (NASA Langley Research Center, Hampton, VA 23665) and R. E. McIntosh (University of Massachusetts, Amherst, MA 01003)

Pessimism has been expressed in the past about the possibility of using microwave Δk-radar techniques to remotely sense ocean surface currents from a satellite platform owing to the motion of the satellite. In this paper we investigate the feasibility of using two dual-frequency radar systems mounted on two geostationary satellites to obtain a map of the surface current vector field over large areas of the ocean.

Our analysis considers the limitations resulting from: (1) the instrument requirements of the system and (2) the physics of the dual-frequency electromagnetic ocean surface interaction. An example is developed which achieves area resolution of 10 km × 10 km assuming worst case parameters for the ocean surface. The system would require less than 100 W of average power and would operate at signal-to-noise ratios approaching the ratio of the energy in the Δk-resonant peak to the energy in the residual Bragg background of the product power spectrum. This latter ratio has been derived (Alpers and Hasselmann, Boundary-layer Met., 13, 215-230, 1978) and can be made greater than 10 dB for the footprint size assumed in our example.

The total signal-to-noise ratio for our example system is shown in the figure below as a function of average radiated power.



SESSION H-1 LABORATORY, SPACE AND FUSION PLASMAS
THURSDAY 8:30 - 12:00
SAN GABRIEL, Room A

INVITED PAPERS

Chairman: N.C. Luhmann, Jr.
Electrical Sciences and
Engineering Department
University of California
Los Angeles, CA

MAGNETIC FIELD LINE RECONNECTION EXPERIMENTS

R. L. Stenzel and W. Gekelman, Department of Physics, University of California, Los Angeles, California

A laboratory experiment on the problem of magnetic field line reconnection in plasmas has been performed. Comprehensive measurements of the magnetic field topologies as well as the plasma dynamics have been performed. The formation of neutral magnetic sheets, tearing, island coalescence and magnetic turbulence will be shown first. Then the force density and ion acceleration have been measured. An anomalous ion collision frequency ν^* has been derived from these quantities and found to be large, $\nu^* \lesssim 0.5\ f_{pi}$, when turbulence is present. Detailed time-dependent measurements of the total electric field and current density vectors have been made from which the plasma resistivity is calculated. The resistivity is found to be spatially inhomogeneous with average values exceeding the classical resistivity on the average by one order of magnitude and locally by two orders. Finally, a careful account of the energy flow is presented showing an efficient transfer from electromagnetic to kinetic energy. The enhanced resistivity, heating and anomalous ion scattering is explained by the presence of a high level of microturbulence. Both magnetic and electrostatic fluctuations are diagnosed in frequency and wavenumber domain and tentatively explained on the basis of current-driven instabilities.

Plasma Waves in Saturn's Magnetosphere*

by

F. L. Scarf

During the Voyager 1 flyby of Saturn in November, 1980, the plasma wave instrument detected many familiar types of waves (ion-acoustic and electron plasma oscillations upstream of the bow shock, bursts of electrostatic noise at the shock, chorus, hiss, electrostatic half-gyrofrequency waves, and upper hybrid emissions in the inner magnetosphere) along with a number of very strong and unfamiliar signals (multiple narrow-band tones, and intense undispersed impulses). A clock-like Saturn rotational control of low-frequency radio emissions was observed, and evidence was obtained of possible control by the moon Dione. Strong plasma wave emissions were also detected at the Titan encounter indicating the presence of a turbulent sheath extending around Titan, and UHR measurements of the electron density show the existence of a dense plume of plasma being carried downstream of Titan by the interaction with the rapidly rotating magnetosphere of Saturn.

*Invited talk for the URSI Meeting, June 17, 1981, Los Angeles

Recent Theoretical and Experimental Progress in Heating in the Vicinity of Ion Cyclotron Harmonics in Fusion Plasmas,* J. E. Scharer, University of Wisconsin, Madison, WI 53706.

Abstract

Plasma heating in the ion cyclotron range of frequencies (ICRF - $\omega_{ci} \sim \omega \lesssim 4\omega_{ci}$) in tokamak and mirror systems is presented. Efficient ion heating at the fundamental minority ion and second harmonic majority ion cyclotron frequencies and substantial electron heating near the two-ion hybrid resonance at up to one megawatt power levels has been obtained in tokamaks using coil antennas. Theoretical examples involving ray tracing, full hot plasma dielectric tensor wave calculations and Fokker-Planck computations for plasma heating provide insight to present experimental results and models for scaling to fusion reactors. Recent tandem mirror experimental results will also be discussed.

* Research supported in part by DOE Contracts ET-79-S-02-5125, DE-AC02-78-ET-51015 and NSF Grant ECS-7920153.

LHRF Heating Experiment in the JFT-2 Tokamak

T. Yamamoto

Japan Atomic Energy Research Institute
Ibaraki, Japan

Heating in the lower hybrid range of frequencies for both ions and electrons in the JFT-2 tokamak is investigated experimentally. An increase in ion temperature of 2-3 eV/kW-10^{13} cm^{-3} was obtained from both charge exchange and doppler broadening measurements with optimized conditions for ion heating. Under conditions for electron heating, the increased electron temperature of 250 eV and 400 eV with irradiated rf power were estimated from laser scattering and soft x-ray measurements, respectively. In a low density plasma, an rf driven current of 110 A/kW, rather than heating the bulk electrons, was observed with rf power of 125 kW.

Particle Beam Experiments in Space

K. Papadopoulos

University of Maryland
College Park Maryland 20742

and

Science Applications, Inc.
McLean, Virginia 22102

A large number of experiments, during the last decade, have utilized rocket born particle accelerators to investigate phenomena connected with magnetospheric and ionospheric structure and dynamics, beam-atmospheric interaction and artificial auroras and fundamental nonlinear plasma processes. The oncoming era of the space shuttle with its associated diagnostic free-fliers, greatly enhances our capability of performing and properly interpreting energetic beam experiments in space. Following an overview of the status of beam and vehicle neutralization, we summarise the challenging question concerning the already obtained results and present a roadmap of future experimental investigation that could lead to their resolution.

Ion Bernstein Waves: Plasma Heating, Ion Temperature Diagnostic and Current Drive Feasibilities,* MASAYUKI ONO, Princeton Plasma Physics Laboratory, Princeton University--Recent theoretical investigations suggest interesting possibilities for ion Bernstein waves in fusion plasmas. Ion Bernstein waves can be used to heat fusion reactor plasmas to ignition temperatures by utilizing simple, reactor-compatible, waveguide rf couplers operating in the ion cyclotron range of frequencies (100-300 MHz). Ion Bernstein wave can be also used to measure space and time resolved ion temperatures in large-hot fusion devices where such measurements become increasingly difficult. In the high temperature burning phase of tokamak-type reactors, ion Bernstein wave has a potential of driving a steady-state toroidal current in the plasma which may make the steady-state reactor operation feasible. Model experiments performed on the Princeton's ACT-1 toroidal research device verified many of these theoretical predictions. Among them are the efficient ion heating at fifth ion cyclotron harmonics, the ion temperature measurement by CO_2 laser scatterings and the unidirectional launching of ion Bernstein waves for the steady-state current drive.

*Work supported by U.S. DOE Contract No. DE-AC02-76-CH03073.

SESSION H-2 WAVES IN PLASMAS
THURSDAY 1:30 - 3:30
SAN PEDRO, Room

Chairman: R.W. Fredericks
TRW
Redondo Beach, CA

IMPEDANCE OF A PLANE CAPACITOR IN A BEAM-PLASMA SYSTEM

Takao Fujita and Saburo Adachi
Department of Electrical Engineering,
Tohoku University, Sendai 980, Japan

An impedance of a plane capacitor immersed in a beam-plasma system is investigated theoretically. The two infinite parallel plates are assumed to be transparent for plasma particles. The non-magnetized beam-plasma system is composed of a cold electron plasma and beam electrons. Electrostatic, linear, non-relativistic fluid approximations are assumed in order to study the fundamental rf characteristics of the impedance. The impedance per unit area of the capacitor is obtained from a potential difference between the two plates and a surface charge density induced on the plates. As an interesting result a negative resistance is resulted below the electron plasma frequency. This is reasoned from the two stream instability. As a special case the impedance of the capacitor in a streaming plasma is obtained by equating the stationary plasma density to zero. This impedance is found to be very similar to the impedance for the stationary plasma having an enhanced equivalent collisional frequency.

SOME AMPLIFICATION PROPERTIES OF ELECTROMAGNETIC mm-WAVES IN A PLASMA TUBE

A. Rosenberg, J. Politch, Y. Ben-Aryeh, J. Felsteiner
Dept. of Physics, Technion-I.I.T., Haifa, Israel

Abstract:

Amplification of e.m. mm-wave radiation within the cathode region of a cold cathode glow discharge was found experimentally. This new phenomena was explained by a model based on stimulated emission of bremsstrahlung from the electrons in the cathode region.

The variation in intensity of the collected radiation as well as the small changes in the discharge current caused by the incident e.m. radiation, were measured along the tube axis from the cathode to anode. The current changes were composed of two opposite effects: a positive one, i.e., an increase in current, which was explained by electron-atom recombination model; and a negative one, i.e., a decrease in current, resulting from the transfer of energy from the fast electrons to the electromagnetic wave. Therefore the negative effect should be proportional to the amplification. This proportionality was found experimentally.

The refraction of the electromagnetic wave by the plasma was measured. Since for radiation frequencies higher than the plasma frequency the refraction index is smaller than one, divergence of the incident wave was found. This divergence has important implications on the technological applications of the amplification phenomena.

Commission F

PULSE PROPAGATION IN DISPERSIVE MEDIA BRILLOUIN'S SIGNAL VELOCITY

R. J. Vidmar
Institute for Plasma Research
Stanford University
Stanford, California 94305

The plane-wave components of one-dimensional wave-packets propagating through an infinite homogeneous medium exhibit three properties: propagation velocity, phase velocity, and growth rate. This analysis of wave-packets excited by periodic sources (such as a continuous-wave source) and transient sources (like a tone burst) establishes Brillouin's signal velocity as a useful velocity that describes the flow of energy for amplifying and evanescent waves (L. Brillouin, Wave Propagation and Group Velocity, Academic Press, 1960). The algebraic expressions for Brillouin's signal velocity in an arbitrary medium depend on the two types of sources considered and whether the plane-wave components maintain their energy, amplify, or decay. The wave properties deduced from wave-packets demonstrate that periodic and transient sources excite amplifying and evanescent waves which have identical frequencies but different signal velocities, phase velocities, and growth rates. The analysis for the amplifying waves in a beam-plasma system exemplifies these source-dependent properties. These results also apply to evanescent-wave phenomena such as ray tracing in an absorptive medium and radar pulses in a lossy media.

A Theory of Coupling Propagation for Electromagnetic and Electron Acoustic Wave in Inhomogeneous Magneto-Plasma.

Chang Man. Zhang Yan- Zheng.

(Institute of Environmental Features. P.O.B. 3928,BeiJing)

Abstract

This paper includes three parts:

(1) Starting from magneto-hydrodynamic linear equations, We have got the coupling propagation eqs. for electromagnetic and electron acoustic wave in inhomogeneous magneto-plasma

$$\alpha_0 \frac{d^2 H_x}{dz^2} - \frac{1}{\epsilon_3}\frac{d\epsilon_3}{dz}\frac{dH_x}{dz} + \left[\frac{\epsilon}{\epsilon_1} k_0^2 - \alpha_1 k_y^2 - \frac{\alpha_2}{\epsilon_3}\frac{d\epsilon_3}{dz}\right] H_x = \frac{\alpha_3}{\epsilon_1}\frac{d\epsilon_1}{dz}\frac{dP_1}{dz} + \left[\frac{\alpha_4}{\epsilon_1}\frac{d\epsilon_1}{dz} k_y - \alpha_5 k_p^2\right] P_1 \quad (1)$$

$$\alpha_0 \frac{d^2 P_1}{dz^2} - \frac{\beta_1}{\epsilon}\frac{d\epsilon_1}{dz}\frac{dP_1}{dz} - \left[k_p^2 + \beta_2 k_y^2 - \frac{\beta_3}{\epsilon}\frac{d\epsilon_1}{dz}\right] P_1 = -\frac{\beta_3}{\epsilon_3}\frac{d\epsilon_3}{dz}\frac{dH_x}{dz} + \left[\frac{\beta_4}{\epsilon_3}\frac{d\epsilon_3}{dz} k_y + \beta_5 k_0^2\right] H_x \quad (2)$$

Then on the selected electron density profiles and boundary conditions, We have given out numerical solutions of $|P_1|$ and $|H_x|$ from eqs. (1)and (2). We have also deducted a Set of simplified and easily Applicable approximate coupling Propagation eqs. Comparing its solutions with the Numerical solutions,We have found that the agreement is very good,with almast no difference.Thereby, fully proved the applicability of this simplified set of eqs.

(2) On the basis of Propagation equation We have been able to give Analytic expresions and Numerical Solutions for convertible Coefficients between optical and Plasma modes under the action of external magnetic field at homogeneous plasma and dielectric baundary.

(3) Finally, under the same conditions We have Computed Bebye lenth and plasma wave lenth,we have Shown that it is Landau damping that causes the incapability of radiation of plasma wave out of plasms sheath, Rather then the Multi-reflections of waves at the strong discontinuty.

At the same time, we have discussed the generality of eqs (1)and (2),and found thet in warm plasma the coupling eqs encompasse the Propagation Coupling Problems, Which have been investigated. i.e,

the homogeneous, isotropic Case[1]; the homogeneous anisotropic case[2] and the inhomogeneous isotropic case[3] Thereby we can think the Coupling Propagation eqs(1)and (2) to be general applicable eqs for wave Propagation Problem in Warm Plasma.

Refrence

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FREQUENCY SHIFT OF A SIGNAL PROPAGATING IN A TIME-DEPENDENT ENVIRONMENT

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As conventionally understood in electromagnetic propagation, the Doppler effect or Doppler shift refers to the difference in frequency between that of a signal observed at a receiver and that of the same signal emitted by a transmitter in motion relative to the receiver. It is a consequence of the purely kinematic requirement that the phase of the signal be invariant under the Lorentz transformation between the proper coordinate systems of the transmitter and receiver. However, the Doppler shift is also understood, particularly in ionospheric propagation, as the change in frequency impressed on a signal propagating along a ray in a time-dependent environment. This second viewpoint suggests that the Doppler effect is a dynamical consequence of the temporal nature of the propagation environment rather than a kinematic effect.

In attempting to reconcile these two viewpoints, we have considered a simple situation which is amenable to calculation by both of the methods alluded to above. A target of conducting material is imagined to be set in uniform non-relativistic motion with respect to a transmitter and receiver separated from each other and relatively at rest. The target intercepts and reflects toward the receiver, a portion of the signal emitted by the emitter. The shift in frequency of the received signal over that of the emitted signal is calculated in a straightforward way from the Galilean principle of invariance and the usual formula is recovered.

The problem is then attacked by the dynamical method. The surface of the target is modeled as a transition layer of underdense plasma which sharply bends the transmitted signal toward the receiver. The frequency shift is then calculated as though it were impressed on the emitted signal in propagating through the "time-dependent" environment created by the moving target. The calculated shift is found to consist of two parts, the conventional kinematic shift, and a part due to the characteristics of the plasma model used in the transition region. The latter part vanishes when the plasma is assumed to be carried along rigidly by the moving target, but not otherwise.

A rigidly co-moving plasma is one example of an incompressible plasma. The present calculation suggests that care should be taken in interpreting the frequency shift of a signal propagating through a time-dependent compressible plasma.

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1982 Symposium

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