W. L. STUTZMAN

NATIONAL ACADEMY OF SCIENCES

NATIONAL RESEARCH COUNCIL

of the

UNITED STATES OF AMERICA

UNITED STATES NATIONAL COMMITTEE
International Scientific Radio Union

URSI

1974 SPRING MEETING
10 – 13 June

Held Jointly With
ANTENNAS and PROPAGATION Society
Institute of Electrical and Electronics Engineers

GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, Georgia

1974 Meeting
Condensed Program

Monday, June 10

0900-1200	VI-1	Electromagnetic Theory	Rm 1, SS Bldg
1330-1700	VI-2	Transient Electromagnetics	Rm 1, SS Bldg
1330-1700	II-1	Propagation: Theory and Experiment	Rm 213, ME Bldg

Tuesday, June 11

0830-1200	VI-3	Antennas and Arrays	Rm 1, SS Bldg
0830-1200	II-2	Turbulence	Rm 213, ME Bldg
1330-1630	VI-4	Spectral Sharing	Rm 1, SS Bldg
1330-1630	II-3	Remote Sensing of the Clear Atmosphere	Rm 2, SS Bldg

Wednesday, June 12

0830-1200	VI-5	Radar Signal Processing Techniques	Rm 1, SS Bldg
0830-1200	VI-6	Numerical Methods I	Rm 2, SS Bldg
0830-1200	II-4	Sea and Land Scatter	Rm 3, SS Bldg*
1330-1710	VI-7 II-5	Radar and Communications Systems: Their Environment and Signal Processing Techniques	Rm 1, SS Bldg
1330-1700	II-6	Remote Sensing of Precipitation	Rm 2, SS Bldg
1400-1600	Sp.	Electromagnetic Education	Rm 3, Phys. Bldg*

Thursday, June 13

0830-1200	VI-8	Diffraction and Scattering	Rm 1, SS Bldg
0830-1200	VI-9 II-7	Polarization and Interference from Precipitation and Clouds	Rm 2, SS Bldg
1330-1700	VI-10	Media Effects on Wave Transmission	Rm 1, SS Bldg
1330-1600	VI-11 II-8	Passive Radiation Techniques	Rm 2, SS Bldg
1330-1640	VI-12	Numerical Methods II	Rm 213, ME Bldg

SPECIAL MEETINGS

Monday, June 10

1700	VI	Informal Business Meeting	Rm 1, SS Bldg

Wednesday, June 12

1700	II	Business Meeting	Rm 2, SS Bldg
1700	VI	Business Meeting	Rm 1, SS Bldg

SS Bldg. - Space Science Building
ME Bldg. - Mechanical Engineering Building
Phys. Bldg. - Physics Building

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* Joint Sessions with AP-S

United States National Committee

INTERNATIONAL UNION OF RADIO SCIENCE

PROGRAM AND ABSTRACTS

1974 Meeting

June 11-13

Held Jointly with

ANTENNAS AND PROPAGATION SOCIETY
INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

Atlanta, Georgia

NOTE

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

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at $2.00 for meetings prior to 1970, $3.00 for 1971 - 1973 meetings and $6.00 for the 1974 meeting. The full papers are not published in any collected format, and 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 are not organized by international URSI, nor are these programs available from the international Secretariat.

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DESCRIPTION OF

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The International Union of Radio Science is one of 14 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; and, (3) to facilitate agreement upon common methods of measurement and the standardization of measuring instruments. 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 International Union has seven permanent bodies called Commissions for centralizing studies in the principal technical fields. In addition, Commission VIII has been established on a provisional basis. The names of the Commissions and the chairmen are as follows:

I. Radio Standards and Measurements
P. O. Lundbom (Sweden)

II. Radio and Non-ionized Media
P. Misme (France)

III. On the Ionosphere
S. A. Bowhill (USA)

IV. On the Magnetosphere
F. L. Scarf (USA)

V. Radio Astronomy
J. L. Locke (Canada)

VI. Radio Waves and Circuits
K. M. Siegel (USA)

VII. Radio Electronics
A. L. Cullen (UK)

VIII. On Radio Noise of Terrestrial Origin
N. D. Clarence (South Africa)

Every three years, the International Union holds a meeting called the General Assembly. The next General Assembly, the XVIII, will be held in Lima, Peru, in August 1975. 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. The International Union 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, for 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 is dependent on radio for its communication link and at the same time expands the scope of radio research. One of its branches, radio astronomy, involves cosmos-wide 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.

COMMISSION II

RADIO AND NON-IONIZED MEDIA

Dr. Isadora Katz, Chairman

SESSIONS PAGE

COMMISSION II

1330 Monday, June 10
Session 1

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Rm 213

PROPAGATION: THEORY AND EXPERIMENT

W. S. Ament, Chairman

II. 1-1 SUBSURFACE ELECTRICAL PROFILE DETERMINATION - THEORY AND EXPERIMENT. R. J. Lytle, E. F. Lain, D. L. Lager, and J. T. Okada, Lawrence Livermore Lab, Livermore, Canada

A variety of cw and swept frequency experiments were performed in a permafrost region of the Brooks Range in Alaska. Two drill holes, 600 feet deep and separated by 550 feet, permitted hole-to-hole and surface-to-hole transmission measurements. Amplitude and phase information was recorded for frequencies of 1-50 GHz. This data enabled determination of the conductivity σ and dielectric constant ε of the subsurface medium between the drill holes for a variety of frequencies. As measurements were taken for numerous depths and relative orientations of source and receiver (both downhole and on the surface), a detailed subsurface electrical profile was obtainable. Least square matrix methods were used to invert the data. Various ways of combining the data yielded equivalent subsurface electrical profiles. This lends credence to the results.

A discussion of the experimental method, theoretical basis of the experiments, data reduction method, and results will be presented. Feasible modes included direct, ground reflected, up-over-down, and anomalie reflected ray paths. These modes were evident (for different source-receiver locations) in the swept frequency interference patterns. A correlation between the geophysical state of the subsurface and its electrical properties was possible. e.g., a permafrost depth of 425' was measured both electrically and thermally.

II. 1-2 PROPAGATION IN NONUNIFORM MULTILAYERED CYLINDRICAL STRUCTURES. E. Bahar, Electrical Engineering Department, University of Nebraska, Lincoln, Nebraska 68508

Due to the lack of rigorous solutions to propagation problems in irregular structures, it is often necessary to idealize significantly the original problem under consideration to obtain tractable solutions. In this paper, we derive full wave solutions to the problem of propagation in irregular multilayered cylindrical structures in order to investigate more suitable models of propagation problems. It is assumed, in this analysis, that the electromagnetic parameters μ and ε and the thickness of the structure's layers are functions of distance along the propagation path. Thus, for instance, this analysis can be applied to problems of diffraction by irregular objects and propagation in the nonuniform cavity between the earth and the ionosphere.

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Rigorous boundary conditions are imposed at each interface of the nonuniform multilayered structure and the solutions are shown to satisfy the reciprocity relationships in electromagnetic theory. Thus, these solutions are applicable over a very wide frequency range and they are not restricted by the concept of a surface impedance which is independent of excitation. At low frequencies, highly conducting earth may be conveniently characterized by a surface impedance, however, it is less justified to represent the lower ionosphere by a sharp boundary characterized by a surface impedance independent of excitation.

II. 1-3 THE SINGULARITY EXPANSION METHOD APPLIED TO A THIN PERFECTLY CONDUCTING DISK. B. D. Graves, T. T. Crow, and C. D. Taylor, Mississippi State University

The Singularity Expansion Method is used to determine the time histories of the currents induced on a thin perfectly conducting disk excited by an arbitrary incident plane wave. The appropriate integro-differential equation is written for the complex frequency, s, and cast into matrix form by standard method of moments techniques. The natural frequencies, mode and coupling vectors, and the time response of the disk are obtained in a straightforward application of the Singularity Expansion Method.

II. 1-4 ON INTERPRETATION AND APPLICATION OF BALK UNIFORM THEORY OF ELECTROMAGNETIC EDGE DIFFRACTION. S. W. Lee, Electromagnetic Laboratory, Department of Electrical Engineering, University of Illinois, Urbana, Illinois 61801

Since J. B. Keller introduced his geometrical theory of diffraction in 1957, a major progress to high frequency electromagnetic edge diffraction has been made in recent years through the development of uniform theory by P. Wolfe (1967), and that by J. Boersma, R. M. Lewis, D. S. Ahluwalia, and P. H. M. Kersten (1967, 1968, 1969). The first purpose of this paper is to give an interpretation to BALK's results for the vector fields. We will write the total field as $\vec{E}^t = \vec{E}^G + \vec{E}^d$. Here $\vec{E}^d$ is precisely the diffracted field in GTD (even though Keller himself found only the first term); thus we have left it unmodified from the non-uniform theory. $\vec{E}^G$ is a <u>modified</u> geometrical optics field, which contains Fresnel integrals and a double series. When observation point is away from the edge and the shadow boundaries, $\vec{E}^G$ reduces asymptotocally to the conventional geometrical optics field $\vec{E}^g$. Otherwise $\vec{E}^G$ becomes infinite in such a way that the singularities in $\vec{E}^d$ are cancelled, and $\vec{E}^t$ is continuous and finite everywhere. The second purpose of this paper is to present a solution of a problem that was obtained by a combination of BALK's theory and the method of modified diffraction coefficient (S. W. Lee; 1970, 1972). The problem is to compute the radiation field from a line source in the presence of two staggered parallel-plates when the source, the observation point, and two edges are on a straight line. Our solution is believed to be new. For the special case when the plates are not staggered and the line source is replaced by an incident plane wave, we recover the exact far field solution obtainable by the Wiener - Hopf technique. When the interaction terms are neglected, our result checks with those of G. A. Deschamps, and D. S. Jones (1970).

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We also compare Balk's theory with Kouyoumjian's theory, and find that these two theories do not agree.

II. 1-5 THEORETICAL AND EXPERIMENTAL SUNRISE MODE CONVERSION RESULTS AT VLF. R. A. Pappert and D. G. Morfitt, Naval Electronics Laboratory Center, San Diego, California 92152

Previously [1] a mode conversion program for VLF was presented which made allowance for both the vertical inhomogeneity and anisotropy of the ionosphere. Horizontal inhomogeneity was modelled by a slab approximation. The required height gain functions were determined by full wave solutions and their associated integrals evaluated numerically. The purpose of the present paper is twofold:

(1) To compare results of that program at several frequencies in the VLF band with experimental sunrise results obtained with a horizontal multi-frequency oblique sounder system located on the island of Hawaii [2]. In particular, comparisons are made with vertical field measurements in southern California.

(2) To simultaneously compare results of a modified mode conversion model with those of the original. In the modified model, height gain functions are discarded above some height h in the guide and are approximated below height h by Airy functions. Merits of the modified version are that a full wave program for height gains is not required and that the associated integrals may be performed analytically. An obvious disadvantage is the free parameter h. The modified mode conversion model can be implemented with about the same ease as a WKB program.

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1. R. A. Pappert and F. P. Snyder (1972 Radio Science, New Series, Vol 7, page 913).
2. D. A. Wulfing and V. E. Hildebrand (1967 Naval Ordnance Laboratory Report 722).

II. 1-6 ATTENUATION FORMULA FOR THE CRITICAL RAY. Thomas A. Croft, Belinda Lipa, Center for Radar Astronomy, Stanford University Stanford, California 94305

When a medium has circular symmetry, it may happen that the refractive index μ decreases with radius r at a rate sufficient to induce "critical ray" curvature that precisely matches the medium's curvature. Critical rays are often of intrinsic interest as, for example, the ray that can circumnavigate the atmosphere of Venus at about 33 km altitude, or ionospheric rays in Earth's E and F layers that travel at constant height.

Even assuming perfect symmetry, it is difficult to derive an expression for the refractive defocussing of a critical ray. Digital computer ray-tracing methods are limited by roundoff error, and furthermore, they would not give the refractive loss

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as a function of the parameters of the medium. We have solved the equation of the eikonal for the critical ray and obtained a simple result: the loss due to defocussing in the vertical plane is $4 \cdot 343 \sqrt{\frac{\partial^2 \mu}{\partial r^2} - \frac{2\mu}{r^2}}$ dB/unit length. The loss in the lateral horizontal plane can be obtained by flux tube reasoning, since rays stay in great circles indefinitely in a symmetric medium. Some applications of this result to Venus and Earth will be described, and derived quantitative conclusions will be presented.

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Session 2

Mechanical Engineering Bldg.
Rm 213

TURBULENCE

J. W. Strohbehn, Chairman

II. 2-1 FREQUENCY SPECTRA OF MULTIFREQUENCY WAVES IN LOCALIZED SMOOTHLY VARYING TURBULENCE. R. Woo, Jet Propulsion Laboratory, Pasadena, California, and A. Ishimaru, University of Washington, Seattle, Washington

The recently launched Mariner 10 spacecraft will fly by the planets Venus and Mercury. A coherent dual frequency downlink operating at 2.3 and 8.4 GHz is provided and will be employed to sense and study the planetary atmospheric turbulence during occultation of the spacecraft.

In this paper, we present the general formulation for the frequency spectra of the fluctuations of plane and spherical waves operating at two frequencies and propagating in localized smoothly varying turbulence. The formulation, based on weak turbulence and frozen-in assumptions, is applied to radio occultation of a fly-by spaceprobe by a planetary atmosphere. The planetary atmospheric turbulence is assumed to exist as a layer, while the localized turbulence is assumed to be described by the Kolmogorov spectrum. Closed-form solutions for the cross spectra and the coherence are obtained for the amplitude at two frequencies, phase at two frequencies, and the amplitude at one frequency with the phase at another. Typical results are shown to illustrate their dependence on the characteristics and extent of the turbulence.

II. 2-2 FREQUENCY SPECTRUM OF A WAVE PROPAGATING THROUGH THE TURBULENT ATMOSPHERE. R. L. Fante, Air Force Cambridge Research Laboratories (AFSC), L. G. Hanscom Field, Bedford, Massachusetts

Using transport methods we have studied the effect of turbulent winds on the frequency spectrum of a wave propagating through the atmosphere. We first considered the case of a plane wave propagating through a medium with a constant wind, V, and found that for large propagation paths, z, the spectrum broadens with distance as $4\, V k_o^{6/5} (C_n^{\,2})^{3/5}\, z^{3/5}$, where k_o is the signal wavenumber and $C_n^{\,2}$ is the strength of the turbulence. (For short paths, the spectrum behaves as $\omega^{-8/3}$ for large ω, since the intensity spectrum is then proportional to the sum of the log-amplitude spectrum and the phase fluctuation spectrum.)

We next considered the case when the wind is not constant but varies along the path. The results for this case are compared with those when the wind is constant.

Finally, we studied the case of a finite beam, rather than a plane wave. Under certain conditions, which we have derived, the spectrum for a beam differs from that for a plane wave. Detailed numerical results will be presented showing the effect of beam area and focal length on the frequency spectrum.

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II. 2-3 TEMPORAL FREQUENCY SPECTRUM OF MULTIFREQUENCY BEAM WAVES IN THE TURBULENT ATMOSPHERE. F. Kavala and M. A. Plonus, Northwestern University

This work is an extension of the previous studies [1,2], on the temporal frequency spectra of the plane and spherical waves, to multifrequency beam waves which are assumed to have a common axis. The development of beam wave analysis is general and incorporates the plane and spherical waves as limiting cases. Temporal frequency spectrum of the log-amplitude and phase fluctuations, cross spectra and coherence for log-amplitude and phase at two frequencies, relationship between beam wave spectrum and plane wave spectrum are given under the assumption of Taylor's hypothesis. The results are studied in detail for Kolmogorov's spectrum in the inertial subrange and by assuming a uniform wind velocity. As $\omega \to 0$ the amplitude spectrum approaches a constant value depending on the frequency and parameters of the beam wave whereas the phase spectrum increases as $\omega^{-8/3}$ and thus, it is not finite as $\omega = 0$. As $\omega \to \infty$, the amplitude and phase spectrum become identical and decrease as $\omega^{-11/3}$. As $\omega \to 0$, the amplitude coherence function reaches a constant value depending on the ratio of the two frequencies, whereas the phase coherence function approaches unity. As $\omega \to \infty$, both coherence functions tends to zero. In general, the asymptotic forms of the spectrum and coherence functions for beam waves behave in a similar way to those of plane waves, except for coefficients which depend on the frequency and the beam wave parameters in a complicated manner.

1. V. I. Tatarski, The Effects of the Turbulent Atmosphere on Wave Propagation, National Science Foundation, Washington, D. C., 1971.
2. A. Ishimaru, "Temporal Frequency Spectra of Multifrequency Waves in the Turbulent Atmosphere," IEEE Trans. Antennas and Propagation, Vol. AP-20, pp. 10-19, January 1972.

II. 2-4 HIGHER MOMENTS OF THE INCOHERENT FIELD IN ATMOSPHERIC SCATTERING. C. I. Beard, Naval Research Laboratory, Washington, D. C.

Some preliminary results are given of the higher moments of the phase quadrature components of the incoherent field measured in atmospheric scattering. In 1968-1969, the phase quadrature components of the 10.4-GHz received signal were measured over a 3.57-km line-of-sight path to a 952-meter high ridge.* As reported previously, the quadrature components of the incoherent field could be approximately described by a bi-variate normal distribution with unequal variances and with correlation in general.

Further analysis has shown the skewness and kurtosis of the inphase component of the incoherent field. Plots are shown of the behavior of the 3rd and 4th moments with rotation of the quadrature axes from the coherent field phase.

* Work done when author was in Boeing Scientific Research Labs., Seattle, Washington

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These plots are compared to Twersky's theoretical calculations and laboratory measurements for spherical scatterers. The distortion of these curves varies with wind speed, and may indicate a sensitivity to the shape of atmospheric turbulence eddies.

II. 2-5 A COMPARISON OF THE TURBULENT FLUCTUATIONS IN CLEAR AIR CONVECTION MEASURED SIMULTANEOUSLY BY AIRCRAFT AND DOPPLER RADAR. Freda L. Robison and Thomas G. Konrad, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland

A comparison between the fluctuations in the horizontal component of velocity measured simultaneously by Doppler radar and aircraft has been made in clear air convective conditions. This experiment is the first in which such a comparison was attempted where the radar return was from fine-scale refractivity fluctuations due to turbulent mixing and not from precipitation particles or artificial scatterers. Good agreement was found between the velocity spectra obtained from Doppler measurements of the variations in the mean wind field and the spectra of velocity fluctuations measured by a hot-wire anemometer. Although the velocity spectrum from Doppler radar measurements is limited to those scales larger than the dimensions of the pulse volume, the comparison with the hot-wire data shows that the spectrum of wind variations for scales smaller than the pulse volume may be confidently estimated by extrapolating the velocity spectrum along a -5/3 slope. This result is further supported by the good agreement found between the predicted level of the velocity spectrum based on the variance of the individual Doppler spectra and the measured velocity spectra from the mean Doppler fluctuations and hot-wire anemometer data.

II. 2-6 A SPATIAL FILTERING TECHNIQUE FOR REDUCING SCINTILLATION NOISE IN OPTICAL RECEIVERS. C. S. Gardner, Department of Electrical Engineering, University of Illinois, Urbana, Illinois 61801

The problem of reducing the received fluctuations of an optical beam wave that has propagated through a turbulent atmosphere is considered. It is assumed that the processing of the received energy can be modeled as a linear spatial operation on the E field in the receiver aperture. A perturbation technique is applied to the result of the linear operation (rather than to the E field) to obtain an expression for the turbulence induced fluctuations. The log-amplitude variance is then calculated using the zeroth-and first-order perturbation terms.

The special case of a linear operator (L) of the form

$$LE = \int_{\text{Aperture}} d\underline{r}\,E(\underline{r})W(\underline{r}) \qquad (1)$$

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where W(r) is a complex receiving aperture weighting function and E(r) is the complex field in the aperture is examined in detail. This operator can be easily implemented using optical spatial filtering techniques. It is shown that the log-amplitude variance can be reduced to zero provided the aperture weighting function, W(r), is appropriately chosen. The properties of the optimum W(r)for a gaussian transmitting aperture distribution are examined with particular attention given to the effects on the log-amplitude variance due to slight perturbations of W(r) about the optimum value. The results indicate that this type receiver may present an effective method for reducing scintillation noise in optical communication systems.

COMMISSION II

1330 Tuesday, June 11 — Space Science Bldg.
Session 3 — Rm 2

REMOTE SENSING OF THE CLEAR ATMOSPHERE

J. Richter, Chairman

II. 3-1 CONVECTIVE PROCESSES OBSERVED SIMULTANEOUSLY BY RADAR, SODAR, AND INSTRUMENTED AIRCRAFT. D. R. Jensen, J. H. Richter, and V. R. Noonkester, Propagation Technology Division, Naval Electronics Laboratory Center, San Diego, California 92152. T. G. Konrad, A. Arnold, and J. R. Rowland, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland 20910.

Convective processes in the atmospheric boundary layer have been studied with various direct and remote sensing techniques. Separate investigations of convective activity have used high-power pulsed radars which provided wide region horizontal and vertical scans, FM-CW radars which provided ultra-high range resolution observations, acoustic sounders (sodar) which provided temperature structure observations compared to moisture structure sensed by microwave radars, and instrumented aircraft which provided direct measurements. Because these sensors have different characteristics and have made independent measurements at different locations, a consistent picture of convection could not be formulated. To resolve these apparent discrepancies a unique experiment was conducted during October 1973. An FM-CW radar and sodar were placed in the vicinity of Wallops Island so that the same volume of a convective region could be simultaneously observed by these two vertical sounders and high-power pulsed radar at Wallops Island. Directly sensed measurements included an instrumented aircraft, rawinsondes, pilot balloons, and surface observations. The purpose of this experiment and the experimental procedure is described in this paper. A companion paper will describe some preliminary results.

II. 3-2 THREE REMOTE SOUNDERS LOOK AT CLEAR AIR CONVECTION. A. Arnold, J. R. Rowland, and T. G. Konrad, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland; and J. H. Richter, V. R. Noonkester, and D. R. Jensen, Naval Electronics Laboratory Center, San Diego, California.

An experiment was conducted to observe, simultaneously, the same region of the lower atmosphere using three sounder systems, a high power pulse radar, an FM-CW radar and an acoustic sounder. Particular attention was directed to the condition when clear air convection dominated the lowest one or two kilometers of the atmosphere. In the past there has been a discrepancy in the description of the convective elements as seen by each sounder individually. The experiment showed that the discrepancy was largely due either to the separate characteristics of the sounders or the ability of one sounder to better observe certain aspects of convection. With this recognition, the upper part of the convective field looked similar to the three sounders. The FM-CW radar and to a lesser extent the acoustic sounder see fine detail; this is largely smoothed out by the pulse radar but the heights and the horizontal dimensions of convective domes are similar when measured with all three sounders. The lower parts of the convective field are seen differently and further resolution of the discrepancy is needed. The return seen by the acoustic sounder is strongest at low altitudes, while the FM-CW radar generally does not see a strong echo. The pulse radar only rarely detects a return at the low altitudes beneath the convective domes.

II. 3-3 SOUNDING THE ATMOSPHERE BY MEANS OF A PURE ACOUSTIC SOUNDER.
H. Dean Parry and Melvin J. Sanders, Jr., NOAA, National Weather Service, Equipment Development Laboratory

Information about the temperature and humidity of the lower atmosphere as a function of height can now be obtained by remote sensing techniques. The pure acoustic sounding system transmits a sound pulse upward and then listens to echoes sent back by the atmosphere to derive information about its temperature structure. A somewhat analogous technique which employs an FM-CW electromagnetic radar obtains information about the humidity structure.

These new remote sensing techniques which were recently used side by side at a location near Wallops Island make it possible to continuously observe both temperature and humidity characteristics of the lower atmosphere. Not only is the remotely sensed information much less expensive to obtain than is information obtained by the conventional radiosonde but the ability of remote sensing systems to continuously monitor the atmosphere makes it possible to establish a real time relationship between changes in EM propagation and the short term variations in the structure of the atmosphere.

Temperature inversions and convections in the atmosphere are detected by the acoustic sounder and the heights of their occurrence are measured. The sounder can follow large scale as well as short term motions of inversion surfaces. The small scale motions are usually undulatory in nature.

II. 3-4 REMOTE SENSING OF WINDS WITH PASSIVE OPTICAL SOURCES.
S. F. Clifford and G. R. Ochs, National Oceanic and Atmospheric Administration Environmental Research Laboratories, Boulder, Colorado 80302 and Ting-i Wang, Cooperative Institute for Research in Environmental Sciences*, University of Colorado, Boulder, Colorado 80302

(Remote sensing of atmosphere and sea using Doppler)

The theory of optical propagation through the turbulent atmosphere shows that irregularities of refractive-index, drifting through the line-of-sight from the source to receiver, produce measurable fluctuations in the beam intensity. This property has been exploited earlier to monitor the path-averaging transverse

* University of Colorado/National Oceanic and Atmospheric Administration

wind speed along a laser-illuminated path. We report on a new technique that requires no active light source, such as a laser or headlight, but only the naturally-occurring ambient illumination of a scene, e.g., a mountainside, clouds, etc. Preliminary theoretical and experimental results indicate the feasibility of continuously measuring the average wind between target and receiver while maintaining a fixed weighting function. The sensitivity of the results to the changing spectrum of the scene and an adaptive technique for controlling the path-weighting will be discussed.

II. 3-5 WIND AND C_n^2 SENSING WITH BOTH RESOLVABLE AND UNRESOLVABLE SETS OF OPTICAL SOURCES. Ting-i Wang, Cooperative Institute for Research in Environmental Sciences*, University of Colorado, Boulder, Colorado 80302 and S. F. Clifford and G. R. Ochs, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, Boulder, Colorado 80302

(Remote sensing of atmosphere and sea using Doppler)

We describe a modification of the optical scintillation technique**, using multiple sources, to measure the transverse wind velocities and strength of refractive turbulence C_n^2 at several positions along the optical path. The width and the location of a path-weighting function can be adjusted simply by changing the separations between the transmitters and between receivers. The resulting weighting functions are insensitive to changes in the spectrum of refractive-index turbulence. However, this technique is mainly limited by signal-to-noise considerations. We discuss the use of both resolvable and unresolvable sources for both the spherical and plane wave cases. This technique is not only useful for providing wind and refractive turbulence profiles along horizontal or slant paths but also provides a reasonable model for testing our ability to use double stars for measuring the turbulence profiles aloft. Experimental measurements of the horizontal path-weighting functions agree with the theoretical predictions.

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* Lawrence, R. S., G. R. Ochs, and S. F. Clifford (1972), "The use of scintillations to measure average wind across a light beam," Appl. Opt., 11, No. 2.

** University of Colorado/National Oceanic and Atmospheric Administration.

COMMISSION II*

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Session 4 — Rm 3

SEA AND LAND SCATTER

D. E. Barrick, Chairman

II. 4-1 ON THE IMAGING OF SEA WAVE WITH COHERENT MICROWAVE RADAR. David L. Drake and John W. Wright, Naval Research Laboratory, Washington, D.C.

An idealized, coherent radar traveling at a speed, V maps a scatterer at a range, R and position X (X parallel to the direction of travel and measured from the axis of radar look) into an imaged position

$$X' = X + U(X)/(V/R)$$

where U(X) is the component of scatterer velocity along the line of sight. Since the number of scatterers $\rho(X)$, say, is conserved in this transformation:

$$\rho(X') = \rho(X) \frac{dx}{dx'} = \frac{\rho(X)}{1 + (V/R) \frac{-1dV}{dX}}$$

Image patterns will thus be formed if either $\rho(X)$ or U(X) varies significantly with X. The former case is analogous to ordinary incoherent optical imaging but the latter is uniquely coherent imaging.

In a two scale model incoherent imaging of sea waves results from tilting of Bragg scatterers by the large wave and by modulation of the Bragg wave amplitude through straining by the large wave. The tilting and straining effects have a similar dependence on large wave slope but the latter has a much different windspeed and Bragg wavenumber dependence. Since, in the two scale case, U(X) is derived from the orbital velocity of the large wave it is quasi-periodic and can also produce a wave-like image by coherent imaging. We have recently examined a number of examples of coherent imagery of the sea for evidence of the above outlined mechanisms and find that we are able to isolate the characteristics of both coherent and incoherent type imagery.

II. 4-2 HIGH RESOLUTION DOPPLER SPECTRA FROM SHORT GRAVITY-CAPILLARY WIND WAVES. T. R. Larson, Naval Research Laboratory, Washington, D.C.

Microwave CW Doppler backscatter spectra from wind waves have been measured in a controlled laboratory environment at 4.283, 9.375, and 23.9 GHz. Independent variables and their ranges were: windspeed, 0 to 15 m/s; fetch, 1 to 10 m; and Bragg water wavelength, 7 to 0.7 cm. The use of parabolic

*Commission II, Session 4, joint with Commission VI, Session 12.

antennas focused in the near field, and digital signal processing and averaging techniques has yielded considerable improvement in Doppler frequency resolution over that previously achieved [1].

The observed spectra contain considerable fine structure at intermediate and higher winds. At the intermediate winds, this is largely explainable on the basis of second order scattering and hydrodynamic effects [2]. The second order splitting is found to be given by

$$\Delta f = f_d \left[1 - \frac{C_g(k_B)}{C_d} \right]$$

where $C_g(k_B)$ is the group speed of the first order Bragg wave and f_d and C_d are the frequency and phase speed of the dominant wave. At higher winds a transition to two scale scattering is clearly discernible in the measured spectra. Crest speeds and optical slope spectra measurements were made to allow comparison of the measured spectra with a two scale model.

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1. Wright, J. W. and Keller, W. C., Physics of Fluids 14(3), 466-474, 1971.
2. Valenzuela, G.R., USNC/URSI Meeting, August 21-24, 1973.

II. 4-3 TRANSIENT RESPONSE OF A CORRUGATED SURFACE. David M. Le Vine, Goddard Space Flight Center, Greenbelt, Md.

A calculation is presented for the signal scattered by a corrugated surface due to a point source above the surface which transmits a short pulse of high frequency radiation. The analysis is restricted to two dimensions and to perfectly conducting, sinusoidal surface, although the approach lends itself to generalization. The analysis is based on the physical optics approximation.

This problem is pertinent, although in a much simplified context, to problems of radar sensing of undulating surfaces, such as a swell dominated sea. In particular, this analysis leads to a definition of the criteria applicable to the use of a short pulse radar to sense the dominate wave structure of a sea.

II. 4-4 RADAR OBSERVATION OF OCEAN WAVE SLOPE SPECTRA. Jerome Eckerman, NASA, Goddard Space Flight Center, and Donald L. Hammond, Naval Research Laboratories

Sensors for remote sensing of ocean wave directional spectra are needed for global wave forecasting application. Backscatter from off-nadir, short pulse, radar-illuminated ocean waves gives the wave impulse response. Wave slope and wave length can be determined from the applitude time radar signature. Analysis of some preliminary wave spectral data taken with a 10 nanosecond aircraft mounted radar will be compared with wave spectra derived from laser prolifometer measurements.

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II. 4-5 RADAR SEA CLUTTER AT 9.5, 16.5, 35, and 95 GHz.
F. B. Dyer, M. J. Gary, and G. W. Ewell, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia 30332

This paper outlines results of investigations of the nature of radar backscatter from the sea at millimeter wavelengths. Included are measurements which span the frequency range 9.4-95 GHz and both horizontal and vertical polarizations; however, the measurements were confined to grazing angles below one degree. A variety of sea conditions were observed. All of the measurement radars were carefully configured to permit accurate measurement of the pulse-to-pulse fluctuations of the radar sea clutter return. In order to reduce variability of results due to changes in environmental conditions, the multi-frequency data were taken simultaneously, and data for the various polarizations were separated by only a few seconds.

Carefully calibrated measurements at 9.5, 16.5 and 35 GHz indicated that the radar cross-section per unit area was generally larger at 16.5 GHz than at 9.5 or 35 GHz, and that the 16.5 GHz return was more sensitive to local environmental conditions. The average return for horizontal polarization was generally less than for vertical at these frequencies. Distributions were approximately log-normal with horizontal having the larger standard deviation.

There were two surprising features of the set of 9.4 and 95 GHz data. The first was reversal of polarization dependence, i.e. vertical having a smaller return than horizontal. The second was that the average radar cross-section per unit area for sea clutter was not significantly higher at 95 than at 9.4 GHz, and for higher sea states, some decrease at 95 GHz was evident.

II. 4-6 SOME COMMENTS ON THE CHARACTERIZATION OF RADAR SEA CLUTTER.
F. B. Dyer and N. C. Currie, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia 30332

Among the more serious and persistent problems encountered in the use of radar in a maritime environment is the masking and/or confusion which results from the presence of sea return. The frustrating nature of sea return, or clutter, has been demonstrated to radar designers time and time again as efforts to develop truly effective automatic detection devices have been less than satisfactory. The key to these devices is the development of clutter processing techniques which provide adequately low false-alarm outputs, while still preserving the return from targets of interest. A fundamental requirement for such developments is that of definitive data on the characteristics of clutter under the wide range of environmental conditions which are possible, and for the span of values potentially available for the various parameters of a radar system.

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This paper addresses several important concepts which have perhaps not received adequate attention in the general literature. Specifically, these are: (1) the wide dynamic range of the return power from a limited area of the sea, (2) the spatially nonhomogeneous nature of sea return, (3) the effects of atmospheric propagation conditions on sea return, and (4) the distortion of information by the measuring equipment. Of special significance here is the case against the use of a single parameter, such as the cross-section per unit area, σ^o, as an estimator for determining detection capability of a radar, particularly if it is based on "averaged" data or "standard" conditions.

II. 4-7 THE GENERALIZED LOMMELL-SEELIGER CROSS SECTION OF A FOLIAGE ENVIRONMENT. C. Donn, Intelcom Rad Tech, Box 80817, San Diego, California 92138, and W. H. Peake, The Ohio State University, Columbus, Ohio 43210

In the upper microwave frequency range, the size of leaves is often larger than the operating wavelength. Hence, the scattering from foliage can be studied by approximating the individual leaf as a plane sheet of uniform thickness, random orientation, and arbitrary shape with the same electrical parameters as the leaf itself. The scattering cross section of a foliage environment (i.e., a volume distribution of randomly distributed leaves) can be found from the generalized Lomell-Seeliger bistatic cross section (GLSBS cross section) of the above leaf model. The GLSBS cross section is given here in an integral representation which takes into account the various polarization states of incident and scattered fields, the scattering geometry, the probability distribution of the leaf orientation, and the effect of both singly and doubly scattered radiation. As a part of the formulation, a convenient expression for the "optical depth" (or penetration depth) of the leaf medium is obtained. Numerical results, based on typical leaf parameters are obtained for the back scattering cross section, and show fairly good agreement with measured cross sections of green and desiccated soybeans at frequencies of 2 GHz, 10 GHz and 35 GHz.

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RADAR AND COMMUNICATIONS SYSTEMS: THEIR ENVIRONMENT AND SIGNAL PROCESSING TECHNIQUES

E. Brookner, Chairman

II. 5-1 THE INFLUENCE OF THE EVAPORATION DUCT ON RADAR COVERAGE.
J. H. Richter & H. V. Hitney, Propagation Technology Division, Naval Electronics Laboratory Center, San Diego, California 92152

Ducting phenomena close to the ocean's surface significantly influence radar coverage conditions. The oceanic evaporation duct which is found nearly all the time over all oceanic areas is of particular importance for over-the-horizon surface to surface radar coverage. An extensive analytical and experimental program has been conducted by the Naval Electronics Laboratory Center with the goal to assess the effect of evaporation ducting from simple in-situ meteorological measurements and to estimate its significance over any oceanic area from long term meteorological statistics. A computer program has been developed which permits calculation of radio propagation in a leaky wave guide. Extensive meteorological and radio propagation measurements in various oceanographic areas were conducted and checked against the computer calculations. Simple meteorological measurements were found to be quite sufficient to describe ducting conditions. Horizontal homogeneity of the duct was found to be good for the propagation paths used in this investigation. Ducting effects deduced from long term meteorological averages compared well with the actual measurements, permitting estimates of ducting conditions to be made for any oceanic area for which such statistical meteorological data are available.

II. 5-2 A COMPARISON OF RADAR ANGLE ERROR CORRECTION TECHNIQUES.
D. C. Thorn, W. R. Cramond, J. E. Leeman, Univ. of Akron

A series of radar observations taken at White Sands Missile Range between 3 August 1959 and 17 April 1961 are used with meteorological data taken in the vicinity of the ray path to provide a basis for studying three techniques for correcting atmospherically produced errors. The three methods compared are the so-called Fannin-Jehn [1], Rainey-Thorn [2], and Bean-Cahoon [3] methods. The radar observations used are quite special in that the target was a beacon geometrically fixed on a mountain. In this paper, based in large part on two internal reports [4,5], we will compare the methods above with one another as well as comparing the geometry indicated by radar observations as corrected by these methods to the actual geometry. Particular attention is given to the limitations imposed on the methods by availability of appropriate (in terms of type, place, and time) meteorological data.

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On the basis of these observations and application of the correction methods it is concluded that the Fannin-Jehn and Rainey-Thorn methods, while differing in many ways, are quite comparable in their end results and are primarily limited only by the quality of available meteorological data. It is further concluded that, while the Bean-Cahoon method is certainly easier to use, it is competitive in accuracy only when limited meteorological data is available.

Azimuth variations recorded on the same test site are reported to justify interest in correction methods which will handle such situations.

Additional experimental designs are proposed to further this work.

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II. 5-3 COMMENTS ON PAPER BY THORN, ET AL. Gordon D. Thayer, NOAA Environmental Research Laboratories

The data on vertical (elevation) angle radar refraction errors presented by Thorn, et al, are in good agreement with the theoretical values given in NBS Tech. Note 44 (Bean, Cahoon, & Thayer, 1960), when adjusted for the altitude of the experiment site. The standard deviation of the azimuthal (horizontal) angle errors is, however, only about one half as large as the expected residual standard deviation of the elevation angle errors after correcting for the expected systematic vertical refractive index gradients, indicating a fairly strong isotropy in the smaller-scale atmospheric refractive index fluctuations. The mean refractive index gradients for the experiment can be derived from the mean absolute angle errors; the mean vertical gradient thus derived is -27 Nkm^{-1} and the mean horizontal gradient (averaged over the path) is $\pm$ 2.5 Nkm^{-1}. The latter value is about an order of magnitude greater than typical synoptic-scale gradients of pressure, temperature, humidity would produce, implying that mesoscale temperature and humidity variations are probably responsible for most of the observed azimuthal angle errors.

II. 5-4 IONOSPHERIC PULSE TIME DISPERSION DUE TO EARTH'S MAGNETIC FIELD. Eli Brookner, Raytheon Company, Wayland, Massachusetts 01778

Previous analyses giving the time dispersion due to the ionosphere on signals having carrier frequencies greater than 100 MHz have neglected the effect of earth's magnetic field [1 - 6]. It is shown that for a linearly polarized signal, conditions can exist where the dispersive effects due to the earth's magnetic field can be appreciable for frequencies up to L-band (1 GHz), the dispersion contributed by the presence of the earth's magnetic field equaling that in its absence. This occurs for the combination of (1) severe ionospheric conditions, (2) a low propagation path elevation angle, and (3) propagation essentially along the earth's magnetic field through the whole ionosphere when the signal is an RF pulse having a Gaussian envelope for which the width is such as to produce 10% broadening in the absence of the earth's magnetic field. For this case a 28 ns wide pulse (3 dB width) is spread 10% for 2.8 ns of dispersion when the earth's magnetic field is neglected, whereas, the effect of the earth's magnetic field itself is to introduce a 2.8 ns dispersion.

The region for failure of the approximation that the earth's magnetic field can be neglected for a linearly polarized signal is specified in detail as a function of ionospheric conditions, path geometry, and allowable pulse width broadening. The time dispersion due to the earth's magnetic field becomes more important when one is concerned with small distortions of the received signal (e.g., only 10% pulse width broadening) rather than large distortions (e.g. 100% broadening). It also increases in significance with increasing severity of the ionospheric conditions.

When using a receiver network for compensation of the pulse time dispersion due to the ionosphere, it may be necessary to have a separate network designed for compensation of the dispersion due to the earth's magnetic field. If the time dispersion not due to the earth's magnetic field is compensated for only, one can in many cases be left with a very large time dispersion due to the earth's magnetic field. For example, assume a radar situation for the above example with two-way propagation instead of one. Also assume that the earth's magnetic field can be neglected (as it could be if it were perpendicular to the signal direction of propagation). Without compensation the minimum pulse width one could transmit before 10% pulse width spreading arises is 40 ns (28 ns becomes $\sqrt{2}$ 28 = 40 ns for two-way

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propagation). Using standard techniques one can compensate for the dispersion in the absence of the earth's magnetic field so as to able to transmit a 200 MHz wide (3 dB points) pulse having a 6.5 ns 3 dB width with only 10% broadening. Thus the residual dispersion is 0.65 ns. However, if the earth's magnetic field is directed essentially along the direction of propagation it will give rise to a dispersion of 5.6 ns, 8.6 times larger than the 0.65 ns residual dispersion (and twice as much earth-magnetic-field dispersion as for the one-way propagation example given above).

A potential technique for compensation of the dispersion due to the earth's magnetic field is presented.

For a circularly polarized signal the earth's magnetic field changes the ionospheric dispersion by only a few percent for the worst case assumptions of a carrier frequency of 100 MHz and propagation along the earth's magnetic field. Hence, except for some instances where compensation for the ionospheric pulse time dispersion is used, the dispersion due to the ionosphere can be neglected for carrier frequencies above 100 MHz when circularly polarized signals are propagated.

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3. E. Brookner, "Effect of Ionosphere on Radar Waveforms", J. Franklin Institute, Vol. 280, pp. 1-22, July 1965.
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II. 5-5 TIME DIVERSITY CODING FOR COMMUNICATION OVER UHF CHANNELS WITH IONOSPHERIC SCINTILLATION. Edward A. Bucher, MIT Lincoln Laboratory*, Lexington, Massachusetts 02173

Diversity techniques combining signals transmitted over diverse coordinates with independent fading often achieve reliable efficient communication with fluctuating signal levels. Theoretical and experimental studies of UHF ionospheric scintillation indicate that neither frequency diversity nor polarization diversity is available for practical UHF satellite communications systems. Moreover, space diversity is available only to those terminals with antenna separations of tens of kilometers. This leaves time diversity coding as the only possible diversity technique for achieving reliable efficient communication with power limited UHF satellites during ionospheric scintillation. This paper discusses several techniques of obtaining time diversity in data communications systems. Implementation of time diversity requires that the receiver have an accurate channel quality measurement. If communication back to the transmitter is possible, time diversity can be obtained by dividing the message into segments comparable to the "average" fade duration and retransmitting upon request those segments obscured by fading. Without feedback, the faded segments must be filled-in using algebraic coding techniques; particularly, direct product codes and burst-trapping codes. Computer simulation of these time diversity techniques against both simulated and measured UHF scintillation are reported. Issues involved in implementing time diversity are also discussed.

*This work was sponsored by the Department of the Navy.

II. 5-6 DIVERSITY SCHEMES FOR UHF IONOSPHERIC SCINTILLATION.* R. K. Crane, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts

Morphological studies of ionospheric scintillation at UHF have shown that scintillation is a fact of life for communication systems operating through either the equatorial ionosphere or the high latitude (auroral and polar) ionosphere. To mitigate the deleterious effect of scintillation the use of one or more possible diversity schemes are often proposed; frequency, space, time and polarization. The effectiveness of each of these schemes was studied using simultaneous UHF (400 MHz) and VHF (150 MHz) measurements between the low orbiting Navy Navigation satellites and the Millstone Hill Radar Facility[1].

* This work has been sponsored by the Dept. of the Navy.

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Simultaneous observations using orthogonal circular polarization channels at UHF show that the fluctuations in the received signal amplitude for each channel were highly correlated and polarization diversity will not work. This result was obtained both for weak and strong amplitude scintillations. The correlation coefficient for simultaneous UHF and VHF amplitude measurements ranged from 0.0 to 0.6 depending upon the elevation angle. At high elevation angles, values near 0.6 were obtained indicating that frequency diversity is of limited usefulness. The data show that either time or space diversity will be useful. The spatial diversity distance is the order of the first Fresnel zone radius and, knowing the path geometry and effective drift rate of the irregularities across the line of sight, the diversity distance or time may be computed.

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II. 5-7 COMPARISON OF MEASURED LORAN-C SIGNALS WITH PREDICTED VALUES. J. D. Illgen, General Electric-TEMPO, Santa Barabara, California, P. K. Carlston, D. E. Hamel, Computer Sciences Corporation, Falls Church, Virginia

The results of an analysis which compares measured LORAN-C (100 KHz pulse-type system) signal characteristics and calculated values (for the once reflected wave) based upon measured election densities shown. Low frequency data obtained from East Coast LORAN-C navigational chain was chosen because of its favorable geographical location with respect to Wallops Island, Virginia.

Direct rocket measurements of the electron density are utilized as an input to the propagation program (subroutine ANIREF) which calculates ionospheric reflection coefficients. The rocket measurement technique and the selection of rocket data obtained are discussed. The reflective properties are then used as inputs to another routine of the propagation program (subroutine ANIHOP) which is used to calculate signal amplitude and phase. The electron density profiles were measured over Wallops Island, which is the midpoint region of the propagation paths of interest. The path Nantucket-Jupiter is a nearly north-south path while Dana, Indiana-Bermuda is an east-west one. The calculated values using the propagation program are then compared to the measured LORAN-C signals. The LORAN-C signals and direct rocket measurements of the electron density were made simultaneously. The comparisons for both the normal and disturbed environments show excellent agreement.

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II. 5-8 COMMUNICATION VIA THE SEA SURFACE. J. C. Hassab, Naval Underwater Systems Center, Newport, Rhode Island 02840

In many instances, the sea surface forms part of a communication link (Hassab, URSI, p. 82, 1973). An analysis has been conducted on the dispersive characteristics of such a rough surface. The Kirchhoff approach is used in the derivation of formulas for the corresponding transfer function. The transfer function is then utilized to assess the relative effect on the channel's capacity and fidelity, of such items as Gaussian and non-Gaussian forms for the distributions of heights and their correlation functions. The implications of the surface's structure to coherent tracking of parameters contained in the specularly scattered signal will be described and illustrated.

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REMOTE SENSING OF PRECIPITATION

R. J. Doviak, Chairman

II. 6-1 VELOCITY SPECTRA OF VORTICES SCANNED WITH A PULSED DOPPLER RADAR. Dusan S. Zrnic* and Richard J. Doviak, National Severe Storms Laboratory, NOAA, Norman, Oklahoma 73069

Doppler velocity spectra of a Rankine model vortex are computed assuming a Gaussian antenna pattern, various vortex sizes, pulse volume depths, and reflectivity profiles. Both very narrow and very broad antenna beamwidths may produce bimodal spectra. In most instances, the theoretically derived spectra exhibit a rapid power decrease for spectral components which is in agreement with an experimental observation previously reported.

In spring 1973, NSSL's 10-cm, high resolution Doppler radar scanned the vicinity of a large tornado that devastated Union City, Oklahoma. Digital radar samples were recorded and Fourier analyzed to derive power spectra for sample volumes spaced about the vortex location. These spectra are compared with those theoretically derived to estimate the velocity field.

* A National Research Council-NOAA Research Associate.

II. 6-2 ATMOSPHERIC PROBING WITH A DUAL DOPPLER RADAR SYSTEM. Richard G. Strauch, Wave Propagation Laboratory, Environmental Research Laboratories, National Oceanic and Atmospheric Administration, Boulder, Colorado 80302

A 3-cm dual Doppler radar system capable of measuring two-dimensional particle velocity fields has been operational at the Wave Propagation Laboratory for approximately two years and has been utilized in a variety of meteorological experiments. Some of the long awaited promise of meteorological Doppler radar has been realized with this equipment. Three-dimensional wind fields can be derived from the measured two-dimensional fields using assumptions about the fall speed of the particles and the continuity equation. The present system has limited data processing capability and utilizes only a small fraction of the total available data. A second generation radar with a minicomputer as an integral part of the radar is now in operation. The minicomputer controls the radar and the experimental procedure in addition to processing data. This radar will be one station in a dual Doppler system that will be able to measure and display particle velocity fields almost in real-time. Wind fields in a convective storm and in a snow storm are shown which demonstrate the future potential of the system for displaying the evolving wind fields in severe storms and thus provide essential data for numerical models of storm dynamics and weather modification processes.

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II. 6-3 ESTIMATION OF RAINDROP SPECTRA USING MULTIPLE WAVELENGTH RADARS. J. Goldhirsh and I. Katz, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland

An analysis is made of the feasibility of using multiple wavelength radar systems to estimate raindrop size distributions. Pairs of radars at 1 and 3, and 1 and 10, and 3 and 10 cm are considered. The methods involve measurements of rain reflectivities at two wavelengths and at two range intervals separated by about 1 km. Assuming a general exponential form for the drop size spectra, equations are developed relating the distribution parameters to the measurements.

The sensitivities of the various systems to errors are elaborated upon in terms of uncertainties in the parameters defining the drop spectra and these are transferred into rain rate errors.

The basic limitations of the systems described are:

(1) Combined measurement errors with two radars of less than 1 dB are required.

(2) A large number of independent measurements (of the order of 10^4) are required to obtain estimates of attenuation coefficients with high confidence levels.

(3) One must average raindrop distributions over range intervals of about 1 km.

(4) The assumption of uniformity of reflectivity at range intervals of about 1 km is implicit in the formulation.

Considering the present state-of-the-art, we conclude that radar inaccuracies as well as other constraints preclude the practical use of multiple wavelength radar systems of the type described to estimate raindrop spectra.

II. 6-4 PRECIPITATION PARAMETERS DETERMINED BY MULTIPLE DOPPLER RADARS AT VERTICAL INCIDENCE. Gene B. Walker, University of Oklahoma, Norman, Oklahoma 73069 and Peter S. Ray, National Severe Storms Laboratory, NOAA, Norman, Oklahoma 73069

A multiple vertically looking Doppler radar technique to estimate storm parameters is presented. The ratio of the velocity power density spectra from two radars of different frequency are uniquely related to the radar scattering cross section ratios at a given temperature. This ratio curve is used to estimate vertical drop velocities and therefore drop-size distributions and vertical wind. Turbulence, which broadens the velocity power spectra, may be estimated by deconvolution prior to computation of drop-size distributions.

II. 6-5 SIMULATION OF DUAL WAVELENGTH DOPPLER RADAR EXPERIMENT TO MEASURE VERTICAL VELOCITY AND DROP-SIZE DISTRIBUTIONS.
Peter S. Ray, National Severe Storms Laboratory, NOAA, Norman, Oklahoma 73069

Estimates of drop-size distributions aloft are sensitive to the errors in the vertical wind estimate. To reduce estimate errors, the technique to deduce vertical velocity from power spectra ratios obtained from two vertically pointing radars at two different wavelengths is examined. Using assumed distributions, ratios of spectra were computed from environments of water, ice, and water-coated ice and are presented for several wavelength ratios. The effects of turbulence, errors in the estimate of drop temperature, and fluctuations in the power spectral estimates are derived for simulated weather spectra. Data processing techniques are suggested and the required sampling time is indicated.

II. 6-6 A NUMERICAL COMPARISON OF FIVE MEAN FREQUENCY ESTIMATORS.
Dale Sirmans and Bill Bumgarner, National Severe Storms Laboratory, NOAA, Norman, Oklahoma 73069

The performance of five techniques for estimating the mean frequency of pulse Doppler signal returns from precipitation is measured in terms of estimate bias, accuracy, and noise immunity. All estimators have been previously introduced in the literature and are presented without derivation. Techniques examined are: (1) Fast Fourier Transform, (2) covariance argument approximation, (3) vector phase change, (4) scalar phase change, and (5) time derivative form of covariance.

All estimators are applied to the same two data sets of uniformly time spaced digital samples of a complex signal. Data sets are: (1) a computer simulated signal having a pseudo-Gaussian spectral density with full control exercised over all pertinent parameters such as mean frequency, standard deviation, signal-to-noise ratio, and number of time samples; and (2) real data in the form of precipitation return from a pulsed Doppler radar.

The absolute and relative performance of each are noted, and numerical results are compared with theoretical calculations made by other investigators. For mean frequency estimation of the signal types examined (narrow, symmetrical spectral densities), the covariance technique is unbiased and superior in terms of accuracy and noise immunity.

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POLARIZATION AND INTERFERENCE FROM PRECIPITATION AND CLOUDS

D. C. Cox, Chairman

II. 7-1 FINE SCALE STRUCTURE OF PRECIPITATION AND EM PROPAGATION: A REPORT ON IUCRM COLLOQUIM.
T. G. Konrad, Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Maryland

A Colloquim sponsored by the Inter-Union Commission on Radar Meteorology (IUCRM) concerning "The Fine Scale Structure of Precipitation and EM Propagation" was held in Nice, France during October, 1973. Following the presentation of the papers in the scientific sessions, working groups were formed which reviewed the state-of-the-art and prepared summary reports with recommendations. This paper will review some of the highlights of the reports of these groups.

II. 7-2 POLARIZATION EFFECTS IN MILLIMETER WAVE SPACE LINKS THROUGH RAIN: A REVIEW OF PRESENT THEORY AND A DISCUSSION OF THE VPI&SU ATS-F POLARIZATION EXPERIMENT.
Robert E. Marshall, C. W. Bostian, W. L. Stutzman, P. H. Wiley, E. A. Manus, and W. W. Farley, Jr., Virginia Polytechnic Institute and State University Blacksburg, Virginia

Millimeter wave rainfall depolarization may limit the effectiveness of future satellite communication systems using orthogonal-polarization frequency sharing. Although present understanding of rain-induced depolarization for ground links is such that reliable predictions can be made, there is little quantitative information existing about depolarization on earth-satellite millimeter wave paths.

The authors are preparing an experiment which will involve monitoring and recording the cross-polarized and co-polarized signals on the ATS-F 20 GHz downlink and relating them to weather data.

This paper will present the details of the VPI ATS-F depolarization experiment and will explain some of the problems associated with gathering millimeter wave depolarization data. A review of existing ground link and space link theory is included.

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II. 7-3 THE EFFECTS OF MEASUREMENT ERRORS ON CALCULATING RAIN PRODUCED CROSS-POLARIZATION COUPLING FOR SIGNALS OF A GIVEN POLARIZATION USING MEASUREMENTS ON SIGNALS OF DIFFERENT POLARIZATIONS. D. C. Cox, Bell Telephone Laboratories, Incorporated, Crawford Hill Laboratory, Holmdel, New Jersey 07733

Measurements of rain produced depolarization for linearly polarized 20 and 30 GHz satellite signals oriented vertical (V) and horizontal (H) and a few degrees either side of V and H are required to determine both the proper polarization orientation for future systems and the depolarization at that orientation. The 20 and 30 GHz beacons on the AT&T communications satellites will provide the capability for making these measurements.

Calculation of rain produced depolarization of one pair of orthogonally polarized signals from measurements of depolarization and differential attenuation and phase of a significantly different pair of orthogonally polarized signals is shown to be quite sensitive to measurement errors. Therefore, it is better to measure the propagation parameters for the polarization orientation for which the parameters are desired. However, useful depolarization information can be obtained by calculation if the satellite configuration requires measurement of propagation parameters at a polarization orientation other than the desired orientation. The accuracies required in the measuring system to insure adequate accuracy in the calculated propagation parameters from measurements at a different polarization are a) error in differential attenuation between the two transmitted polarizations $\leq \pm$ .5 db, b) error in differential phase for the same two signals $\leq \pm 2°$, and c) cross-polarization coupling in measuring system $<$ 30 db. High clear air carrier to noise rations ($>$ 45 db) are required in the measuring system.

II. 7-4 RAIN DEPOLARIZATION AT 4, 6, AND 11 GHz. R. Taur, Comsat Laboratories

The effect of rain upon polarization isolation has been calculated as a function of rainrate, path length and frequencies, including differential phase shift due to oblate raindrops. In order to test the theory, an experiment measuring the rain depolarization of a satellite-to-earth link at 4 GHz was implemented. The experimental values generally agree with the theoretical predictions, but the theory tends to underestimate the effect as compared with the measurements. This is possibly due to some near field effect plus the errors introduced by approximating the raindrops as ellipsoids, especially at high rainrates. Nevertheless, theoretical and experimental values would generally differ at most by 3 dB in the level of depolarization due to rain.

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Three methods of restoring polarization isolation will be presented and their application and feasibility will be discussed. The canting angle correction method is useful for single transmitter and a single receiver communication links and can also be used in determining the optimum polarization orientation for a frequency reusing system. The matching axial ratio method can be used for communication systems reusing frequencies below 10 GHz. For systems reusing frequencies above 10 GHz, orthogonality restoration method must be used.

II. 7-5 RAIN DEPOLARIZATION SCATTER PREDICTION. J. L. Hogler, C. W. Bostian, W. L. Stutzman and P. H. Wiley, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

This paper extends an existing mathematical model of rain depolarization and attenuation to include the expected variances as well as the usually predicted mean values. It emphasizes depolarization and develops data for waves with frequencies ranging from 4 to 34.8 GHz propagating in rain cells which vary in intensity from light to severe. General causes of output scatter are included, and the scatter induced by the rain drop size distribution is examined in detail. Predicted cross polarization variances in excess of 9 dB for certain frequencies are shown. This variance is significant in that it can easily exceed system threshold criteria of mean value designs. Methods for extending the depolarization predictions to attenuation variances are discussed. The paper concludes with a brief examination of resonance encountered when drop diameters are multiples or submultiples of critical wavelengths. Conclusions drawn are applicable to polarization diversity design; multiple hop systems requiring frequency reuse and systems constrained to operate under fixed polarizations.

II. 7-6 TRANSHORIZON INTERFERENCE MEASUREMENTS AT 15.7 GHz. R. L. Olsen, Communications Research Centre, Department of Communications, Ottawa, Ontario, Canada and U. H. W. Lammers, Air Force Cambridge Research Laboratories, Bedford, Massachusetts, U.S.A.

The probability of interference between terrestrial and space communication systems sharing the same frequency bands is presently calculated for conditions of no precipitation using an empirical technique based on measured data. This procedure has not been adequately evaluated at frequencies above 10 GHz and over long paths. An experiment was conducted at 15.7 GHz to obtain the required transmission loss statistics for a 500 km overland path. The use of various antenna scanning procedures and additional Doppler frequency measurements enables the data to be separated according to propagation mechanism. Measurements were made primarily with 9m transmitting and receiving antennas. However, a 1.2m transmitting antenna was also used to determine the amount of gain degradation for various interference levels.

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The analysis of the measurements obtained over a fifteen month period indicates that, for this path, the empirical method underestimates the transmission loss not exceeded for small percentages of the time by an amount which increases with the elevation angle of the earth-station antenna. The predominant interference mechanisms over the path are scattering from turbulent irregularities and hydrometeors, with the latter, due mainly to cloud, producing the higher levels of interference.

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PASSIVE RADIATION TECHNIQUES

W. H. Peake, Chairman

II. 8-1 THE MICROWAVE RADIOMETRIC PROPERTIES OF FOAM.
L. U. Martin, Naval Research Laboratory,
Washington, D.C.

Of primary importance in the study of the microwave radiometric characteristics of foam are the maximum radiometric temperature and it's variation with frequency, polarization and viewing angle. However, the inherent variability in foam depth, bubble size, air/water content and areal coverage among various observations has led to wide variations in results. By making simultaneous dual-polarization measurements at three frequencies of a surf-zone, information on the frequency and polarization dependence of foam has been obtained under a variety of foam thickness conditions.

The measurements were made with a multi-frequency airborne radiometer system using identical seven-degree beamwidths which viewed the same surface area. The measurements were made at vertical polarization at 1.4 GHz and with simultaneous dual polarizations at 8.35 and 14.5 GHz. Viewing angles from nadir to 53 degrees from nadir were obtained during the measurements.

The increase in observed radiometric temperature above the background sea temperature was used as a variable in the data analyses. Results obtained by plotting this temperature increase at L and X-band versus K_u-band for the various viewing angles and polarizations are presented. The results indicate that sufficient foam thickness was observed at the higher frequencies to provide maximum foam temperatures, while large variations in foam temperature were found at L-band. Both polarizations gave near identical foam temperatures at nadir, while horizontal polarization provided a greater temperature increase than vertical polarization with increasing viewing angle.

II. 8-2 APPLICATION OF FOURIER TRANSFORMS FOR RADIOMETRIC INVERSIONS.
F. L. Fisher, C. A. Balanis, J. J. Holmes, W. M. Truman, Department of Electrical Engineering, West Virginia University, Morgantown, and J. W. Johnson, W. L. Jones, B. M. Kendall, NASA, Langley Research Center
Hampton, Virginia

Existing microwave radiometer technology now provides a suitable method for remote determination of absolute brightness temperature measurements. Specifically, the ability to periodically determine, via satellite, the

* Commission II, Session 8 joint with Commission VI, Session 11

surface temperature of the oceans is extremely important. This information has several potential applications in the fishing industry, the marine transport industry, marine meteorology, and oceanography.

Unfortunately, factors other than the surface temperature affect the radiometer brightness temperature. Salinity, surface roughness, and foaming are capable of producing erroneous interpretations of the surface brightness temperature. To control the influencing parameters, the Flight Instrument Division of NASA, Langley Research Center, has established a laboratory wave tank to be investigated using microwave radiometric techniques. Since the experimental facility does not include the vastness of the ocean, several possible sources of error may exist in the setup that will not be of concern in remote environments. The contributions to the apparent antenna temperature from the adjacent earth and sky must be known for all viewing angles so they can be selectively eliminated.

In this investigation the laboratory finite size wave tank system is analyzed assuming a two-dimensional geometry, the resulting integral equations are evaluated using Fast Fourier Transform techniques, preliminary measurements are reported, and inversions are performed on the measurements. Although the method is more accurate for narrow beam antennas, which are usually employed in radiometry, it does represent a computationally efficient and diversified tool. In addition, it casts the equations into a correlation form which is very convenient, in the transform domain, for inversion of experimental measurements. With the recent availability and advances of Fast Fourier Transform techniques, the methods become very attractive in the evaluation of large quantities of data.

II. 8-3 APPLICATION OF INFORMATION THEORY TO THE DESIGN OF RADIO TELESCOPES. William R. Goddard, Space Applications, Communications Research Centre, Ottawa, Canada

An optimum design of a radio telescope for observation of a brightness distribution can be obtained by an appropriate tradeoff between resolution and sensitivity. An observational information theory is used to derive the expected information gain for a scan of the visible sky (one-dimensional). This gain embraces the conventional measures of performance (resolution, and sensitivity), and this gain can be maximized to optimize the telescope performance. We consider the special case of infinite averaging-time. (The general case has been studied).

The simple example of a telescope whose spatial frequency response consists of an equilateral triangle on a rectangular pedestal is used to demonstrate the theory. We show that the maximum average information gain is achieved when the pedestal height is 40% of the maximum spatial frequency response.

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II. 8-4 ESTIMATION OF SOLAR LIMB BRIGHTENING AT RADIO WAVELENGTHS FROM SOLAR ECLIPSE MEASUREMENTS. P. L. Smith, The Aerospace Corporation, Los Angeles, California 90009

The center of limb brightness distribution of the sun at radio wavelengths gives information about the structure of the solar atmosphere. However radio telescopes have poor spatial resolution and cannot provide detailed angular measurements of the brightness distribution. During a solar eclipse, the sharp edge of the moon can be used to greatly increase the angular resolution of the radio telescope in one dimension. This paper describes the techniques used to estimate the brightness distribution from measurements made in the 3mm wavelength region during the total solar eclipse which occured on June 30, 1973. The techniques can be applied to partial eclipses as well. A parametric solar flux density model is formulated and the flux distribution is estimated using the Kalman estimation algorithm. Unlike deconvolution and transform methods, independent and detailed knowledge of the antenna pattern is not required since only relatively short intervals of data are used.

COMMISSION VI

RADIO WAVES AND TRANSMISSION INFORMATION

Dr. Aharon A. Ksienski, Chairman

COMMISSION VI (Continued)

COMMISSION VI

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Session 1

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Rm 1

ELECTROMAGNETIC THEORY

A. Hessel, Chairman

VI. 1-1 THE STRUCTURE OF DYADIC GREEN'S FUNCTIONS AND THEIR EIGENFUNCTION EXPANSIONS. C-T. Tai, Radiation Laboratory, Department of Electrical and Computer Engineering, The University of Michigan

A more refined classification will be given to various dyadic Green's functions encountered in eletromagnetic theory. These functions correspond to the dyadic version of the electric field, the magnetic field, and the vector potential function for point sources. Because of the different characteristics of the differential equations defining these functions, their eigenfunction expansions are also different. Using the rectangular waveguide as an example, it will be shown that the expansion of the magnetic dyadic Green's function is the simplest. Several expansion theorems involving two-dimensional and three-dimensional singular dyadic functions have been derived. These theorems are used in deriving the residue series of the eigenfunction expansions of various Green's functions. The omission of the singular terms in the author's previous work will be pointed out for functions pertaining to different diffracting bodies, including the cylinder, sphere, wedge, cone, and waveguide with a moving isotropic medium.

VI. 1-2 ON THE RESONANCES OF A DIELECTRIC RESONATOR. J. Van Bladel, Laboratorium voor Electromagnetisme en Acustica, Belgium

The resonances are examined in the limit of very high ϵ_r. The modes are of the "confined" or "non-confined" type. Their orthogonality properties and a variational principle are derived. The Q's and equivalent electric or magnetic dipole moments are calculated. The excitation of the resonator by internal volume sources or incident waves is examined. Particularly simple formulas are obtained for the peak value of the moments at resonance, and for the resulting scattering cross-section.

VI. 1-3 ANALYTICAL EXPRESSIONS FOR ERROR BOUNDS IN THE METHOD OF REGULARIZATION IN RECONSTRUCTION PROBLEMS. Hrair S. Cabayan, Intelcom Rad Tech, P. O. Box 80817, San Diego, California 92138, and Raj Mittra, Department of Electrical Engineering, University of Illinois, Urbana, Illinois

In a previous paper [1], the authors have shown how the method of regularization can be used to solve problems of wavefront reconstruction formulated in terms of an integral equation. The problem was posed as follows: Given the knowledge of the field distribution over an aperture, reconstruct the source distribution that produced the field. Computer experiments were reported showing how wavefront reconstruction can be achieved by the method of regularization even when the given data is noisy and how the choice of the regularization parameter is crucial for performing a successful reconstruction.

In this paper, error bounds are derived when estimating the solution function; i.e., the source distribution. For a measurement error level υ, upper and lower bounds are found for the regularization parameter α. Substantiating the previously published numerical results, it is shown that only for values of α within these bounds, will the method yield good recovery of the solution.

Although the method proposed here is deterministic, similarities can be obtained with a statistical approach to the problem. It can be shown that the regularization parameter introduced here plays the same role as the ratio of signal to noise power introduced when the Wiener-Kolmogorov smoothing theory is applied to solving matrix equations problems in the presence of error in the data whose statistical properties are assumed known.

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1. H. S. Cabayan and R. Mittra, "Numerical Aspects of Wavefront Reconstruction," 1970 G-AP International Symposium.

VI. 1-4 NUMERICAL STABILITY AND NEAR-FIELD RECONSTRUCTION IN THREE DIMENSIONAL GEOMETRIES. H. S. Cabayan, Intelcom Rad Tech, and R. C. Murphy, McGill University, Montreal, Quebec, Canada

In electromagnetic inverse scattering problems, it is often necessary to reconstruct the near fields assuming that the far-fields are given. Usually this is achieved by analytic continuation of the far-fields into the near-fields. As is often the case, the far-fields are measured and are therefore known only with a certain degree of accuracy. These small measurement errors may lead to inaccurate near-field reconstruction if special care is not taken on how the numerical reconstruction is carried out. The authors [1] had previously considered the numerical reconstruction problem for two-dimensional geometries where upper and lower bounds were derived on the number of Fourier components N required for accurate field convergence. There it was shown that N depends on both the distance from the origin of the near-field reconstruction point and the error level $\bar{\epsilon}^2$ which arises from errors in the data. This method has presently been extended to three dimensional reconstruction problems. Equivalent expansions for the fields are derived and appropriate criteria for stability are obtained.

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1. H. S. Cabayan and R. C. Murphy, "Numerical Stability and Near-Field Reconstruction," IEEE Trans. Antennas Propagation, Vol. AP-18, pp. 663-642, Sept. 1970.

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VI. 1-5 THEORETICAL PREDICTION OF ELECTROMAGNETIC NEAR-FIELD DISTRIBUTION OF TWO-DIMENSIONAL OBJECTS FROM KNOWN FAR-FIELD DATA. S. J. Hamada, TRW Systems Group, and C. W. Yeh, University of California, Los Angeles

The purpose of the research study was to develop an analytical means for predicting the near-zone electromagnetic field distribution of two-dimensional objects from known far-zone field data.

To obtain the fields, the homogeneous vector wave equation is first solved in free space. Solutions to the homogeneous vector wave equation are described completely by the superposition of cylindrical wave functions and their derivatives. Discrete fourier analysis technique is used to determine the modal coefficients by matching the known far-fields on a cylindrical surface. Once the modal coefficients are determined, the electromagnetic field can then be reconstructed at any intermediate distance from the source. This distance must be greater than the radius of the smallest cylinder enclosing the source.

The validity of this analytical technique is verified by using well established theory of Mathieu functions. The exact solutions of the classical infinite slit configuration in terms of Mathieu functions has been solved by Morse and Rubenstein [1]. These exact solutions are used to verify the analytical technique. The numerical investigation shows that serious numerical problems in the transformation of the far-field to the near-field can be avoided by properly truncating the cylindrical wave expansion.

Also, a complete treatment of existing two-dimensional classical electromagnetic scattering problems (G.T.D., Vector Integral Formula, and Helmholtz and Kirchoff's Integral Theorem) are performed numerically using this analytical technique.

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1. Morse, P. M. and P. J. Rubenstein, "The Diffraction of Waves by Ribbons and Slits," Physical Review, Vol. 54, pp. 895-898 (December 1938).

VI. 1-6 MUTUAL ADMITTANCE BETWEEN NARROW SLITS ON A CONCAVE, CIRCULAR CYLINDRICAL SURFACE. Wasyl Wasylkiwskyj, Institute for Defense Analyses, Arlington, Virginia

This paper deals with the determination of mutual admittance between narrow slits on a concave, perfectly conducting, circular cylindrical surface. To isolate the direct contribution to mutual admittance from that due to reflections within the cylindrical cavity, a "perfect" planar absorber is postulated along the cylinder diameter. Finiteness of the field at the origin requires the spectral representation of the characteristic Green's function to possess, in addition to a discrete spectrum comprising a finite number of Whispering Gallery modes, also a continuous spectrum. The latter is a factitious result, related to the properties of the cylindrical coordinate system and appears to introduce conceptual difficulties of interpreting the solution in ray optical terms. One approach is to place at the origin a small cylindrical scatterer, thus rendering the spectrum purely discrete [1]. The technique adopted herein involves the construction of an approximate, high frequency form of the Green's function, comprising only a finite number of Whispering Gallery modes. This representation is readily transformed into an (infinite) geometrical optics ray series. The series diverges when the source and observation points approach the cylinder surface, where the Whispering Gallery mode series constitutes a suitable form for numerical computation. Numerical results are presented for mutual admittances as a function of element separation for several cylinder radii.

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1. L. B. Felsen, Polytechnic Institute of New York, Private Comm.

VI. 1-7 ANALYSIS OF THE ELECTRON DENSITY PROFILE IN A CYLINDRICAL PLASMA COLUMN BASED ON THERMAL RESONANCES.
Jack G. Olin and Kun-Mu Chen, Department of Electrical Engineering and Systems Science, Michigan State University, East Lansing, Michigan 48824

The electron density profile and other plasma parameters of a cylindrical warm-plasma column are studied through the excitation of thermal resonances using an electron-acoustic probe. The electromagnetic field from the probe excites a series of thermal (Tonks-Dattner) resonances as the current density is varied.

For each driving frequency, the dipole resonance and the first three T-D resonances are recorded. In this study, it is sufficient to measure the relative magnitudes of the plasma densities at which these resonances occur in order to determine the density profile and other plasma parameters such as the temperature and the number density.

In the determination of the plasma density, the thermal resonances are used to determine the unknown parameters appearing in the solution of Poisson's equation in the plasma column. The boundary conditions for the thermal resonances in the plasma column are derived and the total phase for the thermal resonances is determined using the WKB approximation. The dipole resonance is used to determine the average electron density in the plasma column.

The analysis leads to numerical values for the electron density profile parameters, the wall potential and the electron temperature. Graphs for the thermal resonances are also presented.

VI. 1-8 PULSE COMPRESSION IN BOUNDED DISPERSIVE MEDIA.
A. C. Raptis, Joseph T. Mayhan* and C. S. Chen, Electrical Engineering Department, The University of Akron, Akron, Ohio 44325

The pulse compression problem through the bounded dispersive media is considered. In this paper, the transfer function characterizing the bounded dispersive media

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is derived and the group velocity concept is used to synthesize a frequency-modulated input pulses based on the phase characteristics of the transfer function such that the energy in the trailing portion of the pulse will propagate through the media with greater group velocity than that in the leading portion of the pulse resulting in an output with enhanced amplitude at a specified point.

The output pulse was obtained with the aid of the Fast Fourier Transform and the compressed output pulse is compared with that of the transmitted signal through the unbounded media, which was reported in the literature. It is shown that the effects of the boundaries are the slight reduction in amplitude and the additional ripples in the output pulses due to the multiple reflections from the boundaries. The Geometrical Optics Concept is utilized to help demonstrate the interrelationship of the bounded and unbounded media transfer functions.

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*Dr. Mayhan is now with MIT Lincoln Laboratory.

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TRANSIENT ELECTROMAGNETICS

G. F. Ross, Chairman

VI. 2-1 A SPACE-TIME INTEGRODIFFERENTIAL EQUATION SOLUTION FOR SCATTERING BY OPEN THIN SURFACES. K. S. Menger, C. L. Bennett, D. Peterson, and C. Maloy, Sperry Research Center, Sudbury, Massachusetts

A new technique for the numerical solution of time domain integral equations is applied to the problem of determining the currents on open thin surfaces with arbitrary time-dependent excitations. A space-time integrodifferential equation is obtained for the surface currents on a thin perfectly conducting surface by applying the E-field boundary condition. The form of this equation is such that it specifically displays the wave nature of the surface currents, and thus, provides useful insight into the transient mechanism even before the numerical techniques are applied. The actual solution of this equation for a particular problem is carried out on a digital computer after a numerical representation of it has been obtained which reduces the equation to a recurrence relation in time. Results for rectangular plates, circular plates, and cylinder sections will be presented and compared with direct time domain measurements. The numerical computations are in good agreement with experimental measurements for these targets.

VI. 2-2 NUMERICAL SOLUTION OF THE SPACE-TIME INTEGRAL EQUATION FOR SCATTERING FROM SOLID CONDUCTING BODIES WITH EDGES. C. L. Bennett and D. Peterson, Sperry Research Center, Sudbury, Massachusetts

In the past, solution of the space-time integral equation for solid conducting bodies had been accomplished by reducing it into the form of an explicit recurrence relation in time. The solution was then obtained by "marching on in time" using a digital computer. Using this approach, however, required that the minimum distance between space sample points must be greater than the time increment in order to satisfy stability requirements for the solution. Therefore, from a solution efficiency standpoint, this approach implied equal spacing of sample points on the surface.

This paper presents an implicit approach which uses an implicit recurrence relation in the solution procedure. This approach no longer requires that the time increment be less than the minimum distance between space sample points and thus, is well suited for targets with edges. This approach permits the unequal spacing of sample points on the surface and allows a greater density of points where the current is known to vary more rapidly. At each time step, however, the surface current must be solved by the solution of simultaneous equations. This is carried out efficiently from both a computer time and memory usage standpoint by use of iteration. Results obtained with this numerical technique are in good agreement with theoretical results for the case of the wedge geometry. Results will also be presented and discussed for some solid conducting bodies with edges.

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VI. 2-3 TIME DOMAIN APPROACH TO INVERSE SCATTERING. R. Hieronymus, C. L. Bennett, and J. D. DeLorenzo, Sperry Research Center, Sudbury, Massachusetts

In the past, much work has been done on the solution of the inverse scattering problem. Most of this effort has been carried out in the frequency domain. The work, which has been in the time domain, has been based on the assumption that the currents set up on the surface are given by the physical optics approximation. This yields the approximate result that the projected area function of a target is equal to its ramp response.

The purpose of this paper is to present an exact relationship between the target ramp response and the target geometry for the rotationally symmetric scattering problem. The relationship is in the form of a space-time integral equation that may be solved numerically. The first-order solution of this equation turns out to be exactly equal to the solution that one obtains by using the physical optics approximation. Thus, this space-time integral equation may be viewed as the physical optics approximation solution plus the correction terms that provide the exact solution. The numerical solution of this equation will be described and results will be presented for several rotationally symmetric targets. For the case of the sphere, the results obtained with this procedure is in good agreement with the actual geometry.

VI. 2-4 RECENT ADVANCES IN TIME-DOMAIN MEASUREMENT TECHNIQUES. C. L. Bennett, H. M. Cronson, and A. M. Nicolson, Sperry Research Center, 100 North Road, Sudbury, Massachusetts

Over the past several years, precision techniques have been developed for the measurement of subnanosecond transient responses of microwave components and materials, and for the measurement of free-space scattering responses of targets. Recently these techniques have been further improved by development of waveform generators which enhance the higher frequency component of the incident pulse, permitting accurate measurements of responses whose frequency content can span 0.1 to 18 GHz. After a brief overview of the time-domain metrology area, particular descriptions will be given of scattering measurements, time-to-frequency domain characterization of microwave components to 18 GHz, and measurements of complex permeability and permittivity of ferrites to 16 GHz.

VI. 2-5 TRANSIENT FIELDS OF SOURCES LOCATED ON A PLANAR SURFACE. Charles E. Smith, Electrical Engineering Department, University of Mississippi, University, MS 38677

This paper presents expressions and computations for both the far and near transient fields of a planar array of sources with elements having known electric field distribution located on an infinite, perfectly-conducting, plane. In this study, a formulation of the time-history of an array of N infinitely-long slots for a step response excitation is obtained in terms of an equivalent magnetic surface current density. The space-time Green's function for the two-dimensional solution of the related scalar wave equation for a single line source is used to derive this formulation which is shown to be expressible in closed form for the magnetic field of a single slot source. The corresponding expressions for ρ and φ components of the electric field are derived directly from the magnetic field representation. These field expressions are derived from superposition or convolution type integral forms from which it can readily be seen that the time-histories have finite risetimes and long decay-times which are a direct result of the two-dimensional Green's function. The single-slot source has been studied extensively, and numerical data are presented for both single- and multi-element arrays for constant field excitation over the source aperture as a function of source width and spacing and angle of observation. The formulations for the fields of these slot apertures can be used for time-domain synthesis using the superposition of the step function responses, and the integral forms can be extended for field computation related to arbitrary aperture distributions.

VI. 2-6 PULSE RESPONSE OF THICK AXIALLY SYMMETRIC MONOPOLES.

K. A. Al-Badwaihy and J. L. Yen, University of Toronto

The axis extended boundary condition scalar potential integral equation and the Fourier transform are used to study the transient response of thick axially symmetric monopoles. The monopole geometries studied are the hemispherically-capped thick cylindrical monopoles with or without conical feed sections and the duo-conical monopole. The integral equation is solved numerically using the moment method with entire domain basis functions.

The transient response of an infinitely thin dipole and the relaxation of an initial charge distribution on a perfectly conducting sphere are considered to provide a simple physical insight into the process of motion and diffusion of the input current waveform as it moves along the monopole. A general field relation satisfied by the electromagnetic field waveforms is also considered.

The pulse response for each monopole considered includes waveforms of the feeding line reflected current, the radiated field in different directions and the instantaneous current distribution on the monopole. The seven monopoles studied can all be considered as large surface area radiators in comparison with thin dipoles and loops analyzed before.

The radiated waveforms of some of the above mentioned monopoles are presented for a double exponential input voltage waveform with a fast rise and a slow decay to justify a prediction that such waveform with large area radiators can provide a "good" radiated pulse, i.e., a radiated field waveform having a principal positive pulse and a diffused negative tail.

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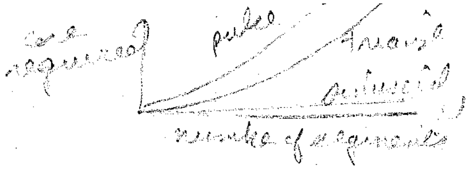
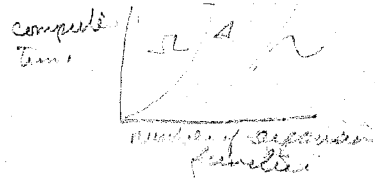
VI. 2-7 NATURAL FREQUENCIES AND NATURAL MODES OF A THIN CONDUCTING CYLINDER ABOVE A PERFECTLY CONDUCTING GROUND. Thomas H. Shumpert, The Dikewood Corporation, Albuquerque, New Mexico 87106

The natural frequencies and natural modes of a thin perfectly conducting, finite-length cylinder above a perfectly conducting ground plane are determined. These natural frequencies (singularities) and natural modes are fundamental parameters in solving an electromagnetic scattering problem using the Singularity Expansion Method (SEM).

Previous investigators have limited their determination of these SEM parameters to geometries where the scattering elements are either parallel to or perpendicular to the conducting ground plane. However, this analysis treats the thin cylindrical scatterer in any orientation above the ground plane using the appropriate Green's function and well-known image theory.

The natural frequencies and natural modes are determined numerically from an integral equation formulation using the method of moments. Results are presented and discussed for several different scatterer orientations and scatterer shape parameters.





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ANTENNAS AND ARRAYS

C. H. Walter, Chairman

VI. 3-1 A COMPARISON OF THREE COMPUTER PROGRAMS FOR THIN-WIRE ANTENNAS. Thomas E. Baldwin, Advanced Programs Group, Atlantic Research Corporation, Alexandria, Virginia 22314, and A. T. Adams, Department of Electrical and Computer Engineering Syracuse University, Syracuse, New York 13210

Three computer programs designed to treat radiation and scattering problems for thin-wire structures by the method of moments [1] have been compared extensively with each other and with experimental data. Each of these three programs is well documented [2] - [5]; they represent a variety of different techniques. For example, pulse, triangle, and sinusoidal expansion functions are used, respectively, in the three programs.

The programs have been compared on the basis of the following:

Current distributions on wire structures, such as dipoles, loops, folded dipoles, wire crosses, dipoles plus parasitic, dipole arrays, etc.

Near fields of dipoles.

Computer core and auxiliary storage requirements.

Central processor time.

The following additional comparative studies were also performed:

Convergence was studied as a function of subsection length and antenna length.

A study of reciprocity relationships was made.

Different solution techniques for the matrix equation are compared.

Different methods for near field computation are compared.

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1. R. F. Harrington, "Field Computation for Moment Methods," Macmillan Co., New York, 1968.
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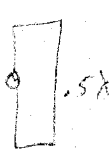

— If segments are smaller than a diameter strange things happen.
— adjacent segments should have a 2:1 ratio
— segments should be $0.01\lambda \le \Delta l \le 0.1\lambda$

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5. D. C. Kuo, H. H. Chao, J. R. Mautz, B. J. Strait, R. F. Harrington, "Analysis of Radiation and Scattering by Arbitrary Configurations of Thin Wires," IEEE Trans. on Antennas and Propagation, Vol. AP-20, No. 6, pp 814-815, Nov. 1972. Program and description on deposit: ASIS-NAPS Document No. NAPS-01798.

VI. 3-2 DIELECTRIC COATED WIRE ANTENNAS.* J. H. Richmond and E. H. Newman, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, Columbus, Ohio 43212

The problem considered is an electrically thin dielectric insulating shell on an antenna composed of electrically thin circular cylindrical wires. The solution is a moment method solution and the insulating shell is modeled by equivalent volume polarization currents. These polarization currents are related in a simple manner to the surface charge density on the wire antenna. In this way the insulating shell causes no new unknowns to be introduced, and the size of the impedance matrix is the same as for the uninsulated wires. The insulation is accounted for entirely through a modification of the symmetric impedance matrix. This modification influences the current distribution, impedance, efficiency, field patterns and scattering properties. The polarization currents generate a highly localized field which may be neglected in far-zone field calculations. The theory will be compared with measurement for dielectric coated antennas in air and water.

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*This work was supported in part by Grant NGL 36-008-138 between National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, and the Ohio State University Research Foundation, Columbus, Ohio.

VI. 3-3 ON THE MULTITURN LOOP ANTENNA. Clayborne D. Taylor, Mississippi State University, Mississippi State, MS 39762, and Charles W. Harrison, Jr., General Electromagnetics, Albuquerque, N.M. 87110

The multiturn loop antenna has important applications as both a transmitting and a receiving antenna, primarily because the volume occupied by the antenna is not required to have dimensions comparable to the operating wavelength. In this paper a multiturn loop in the form of a circular helix is considered, and a general theoretical-numerical formulation is presented.

An integro-differential equation is derived for obtaining the antenna current by considering the structure to be driven from a magnetic current source. The magnetic current source is chosen to represent as nearly as possible an actual feed configuration. By using the method of moments a numerical solution is obtained for the antenna current. Since the formulation allows the windings of the loop antenna to be finitely conducting the antenna efficiency is also available. Furthermore, the antenna pattern is determined.

Numerical results are presented for loop antennas with up to 5 turns. Comparison is made with measured data as well as other available theoretical data.

VI. 3-4 OPTIMUM ELEMENT LENGTHS FOR YAGI-UDA ARRAYS. C. A. Chen and David K. Cheng, Electrical and Computer Engineering Department, Syracuse University, Syracuse, N.Y. 13210

An analytical method is developed for the maximization of the forward gain of a Yagi-Uda antenna array by adjusting the lengths of the array elements. The effects of a finite dipole radius and the mutual coupling between the elements are taken into consideration. Currents in the array elements are approximated by three-term expansions with complex coefficients which convert the governing integral equations into simultaneous algebraic equations. The array gain is maximized by the repeated application of a perturbation procedure which adjusts the lengths of all array elements simultaneously. It is a systematic procedure which converges rapidly and which does not rely on the interpretation of a vast collection of computed data. The key to this method is the establishment of a relation which assures that a properly perturbed array yields an increased gain. The lengths of an array optimized for a maximum gain, in general, are all different. This method can be combined with the procedure for finding the optimum element spacings [1] to yield a max.-max. design. Numerical examples showing gain improvements, current distributions, and radiation patterns will be given.

1. D.K. Cheng and C.A. Chen, "Optimum element spacings for Yagi-Uda arrays," IEEE Trans. on Antennas and Propagation, vol. AP-21, pp 615-623, September 1973.

VI. 3-5 NEAR FIELDS OF BROADSIDE AND ENDFIRE ARRAYS. A. T. Adams, Dept. of Electrical and Computer Engineering, Syracuse University, Syracuse, N.Y. 13210, and Thomas E. Baldwin, Jr., Advanced Projects Group, Atlantic Research Corp., Alexandria, Va.

The near fields of a linear array of dipoles have been analyzed using moment methods. The principal H-plane near fields of broadside and endfire arrays are described in detail. The broadside near field beam patterns narrow, whereas the endfire beam patterns broaden, as r, the distance from the array center, decreases. The near field patterns smoothly approach the far field pattern as r increases. The very near fields of an array and resultant radiation hazards are significantly affected by mutuals, and thus depend on dipole length and spacing. Radiation hazards are more severe for endfire than for broadside arrays. Mutuals have the effect of smoothing out variations in the near field. Decreasing the mutual effects, i.e., isolating the antennas from each other, tends to increase variations in the near field, either in the form of increased null depth or narrower beams. The computed data on near fields of arrays has been compared with experiment and reasonably good agreement has been obtained. The computer program used has been described in the literature [1]. Radiation hazard contour plots may readily be obtained from the data provided by one of the subroutines.

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1. D. E. Warren, T. E. Baldwin, and A. T. Adams, "Near Electric and Magnetic Fields of Wire Antennas," IEEE Trans. on Antennas and Propagation, vol. AP-22, No. 2, March 1974. Program and description on deposit: ASIS-NAPS Document No. NAPS-02221.

VI. 3-6 ELEMENT PATTERNS FOR MATCHED INFINITE LINEAR ARRAYS OF ARBITRARY RADIATORS. Wasyl Wasylkiwskyj, Institute for Defense Analyses, Arlington, Virginia, and Walter K. Kahn, The George Washington University, Washington, D.C.

In an infinite planar array comprising arbitrary radiators the element pattern $\hat{P}(\theta,\varphi)$ in the terminated array environment is given by Hannan's formula $\hat{P}(\theta,\varphi) = (A/\lambda^2)\cos\theta(1-|\rho|^2)$ [1], where ρ is the active reflection coefficient and θ the angle measured from broadside. Evidently, if the active reflection coefficient is reduced to zero for all pointing angles in the visible region by an appropriate matching technique, the pattern of a single excited element in the terminated array environment assumes the canonical form $\hat{P}(\theta,\varphi) = (A/\lambda^2)\cos\theta$. The special case of Hannan's formula, applicable to linear arrays of point sources, has only recently been given by Wasylkiwskyj and Kahn [2]. Unlike for the planar array, no unique canonical result obtains for the matched linear array. On the contrary, the element pattern for each matched linear array depends on the nature of the radiating element. If the radiating element is specified by its radiation pattern in an open circuit (reactive) array environment, the element pattern in the environment of a perfectly matched terminated array is defined uniquely. The latter pattern constitutes an upper bound on the gain versus scan envelope for an imperfectly matched array, and plays a role similar to the $\cos\theta$ factor in Hannan's formula. Numerical results are presented for several classes of elements.

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1. P. W. Hanna, "The Element-Gain Paradox for a Phased Array Antenna," IEEE Trans. Antennas and Propagation, Vol. AP-12, No. 4, pp. 423-433.
2. W. Wasylkiwskyj and W. K. Kahn, "Element Patterns and Active Reflection Coefficient in Uniform Phased Arrays," to be published in the IEEE Trans. Antennas and Propagation.

VI. 3-7 THE POWER-LAW Y ARRAY FOR SUPERSYNTHESIS. Y. L. Chow, University of Waterloo, on Sabbatical at the National Research Council, Ottawa, Canada

To have uniform hole densities in the transfer functions of a Y (shaped) array, Chow [1] has shown that the element positions along the array arms should follow the square-law. The conclusion, however, has neglected the effect of the transfer function edge. This paper shows geometrically that the edge effect becomes important at long tracking time. Hence in this case, a few more elements should be concentrated near the tips of the array arms.

In the 27-element array of NRAO [2], such concentration is arrived at through the "pseudodynamic programming" technique. In the array of this paper, the same is arrived at through reducing the power-law of element positions. The actual power depends on the chosen length of tracking time.

Although both the NRAO and the 1.6 power-law Y arrays give similar nearly optimum accumulated hole densities, the power-law array has smoother hole distribution. More significantly, for the same four adjustable beamwidths, the power-law enables the latter array to require only 70% of the observing stations. Thus the paper points out a possibility of reduction in construction cost. Further, it also points to a corresponding reduction in operation cost before and after the NRAO array is completely built.

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1. Y. L. Chow, "On designing a supersynthesis antenna array," IEEE Trans. on Ant. and Prop. Vol. AP. 20, pp 30-35, Jan. 1972.
2. The National Radio Astronomy Observatory, "A proposal for a very large array radio telescope" Vol. III, chapter 3, Jan. 1969.

VI. 3-8 A BASIC THEOREM CONCERNING THE ELECTRONICS SCANNING CAPABILITIES OF ANTENNAS. John J. Stangel, Sperry Gyroscope Division, Sperry Rand Corporation, Great Neck, New York

This paper considers an electronic scanning antenna as a passive N-port network. Scanning is accomplished by altering the complex excitations at these ports by switches and/or phase shifters. By applying the basic principles of network theory to this conceptual model, a fundamental relationship between the scanning characteristics of the antenna and the number of ports, and hence the number of active devices is derived:

$$N \geq \frac{1}{4\pi} \oiint G_o (\theta,\varphi) d\Omega$$

where $G_o(\theta,\varphi)$ is the maximum gain achievable by the antenna in the (θ,φ) direction. The conditions for realizing a minimum number of active devices in the array (the equality condition in the above equation) are discussed. In addition, the implications of this theorem to the design of planar phase arrays and "limited scan" arrays are discussed in detail.

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SPECTRAL SHARING

J. A. Aein, Chairman

VI. 4-1 TECHNICAL FACTORS IN SPECTRUM SHARING AND UTILIZATION.
J. M. Aein, Institute for Defense Analyses, 400 Army Navy Drive, Arlington, Va. 22202

The existing conjestion in the VHF radio band and expected crowding in the higher bands due to anticipated implementation of expanding microwave telephony, mobile radio, navigation, air traffic control and satellite communication systems has focused considerable concern in governmental bodies and industry on problems of spectrum management, e.g., allocation, monitoring, enforcement, etc. Policy and regulation of spectrum utilization must have a heavy reliance on multi-disciplinary technical information whose components should be co-ordinated. Spectrum sharing requires the prediction and control of interference between systems. This, in turn, depends on (1) phenomological effects of transmission and path coupling; (2) technology of system components with signal design/processing, and (3) assessment of performance degradation. The purpose of this paper is to provide an overview of the technical disciplines involved and their possible relationships. The U.S. domestic satellite systems are used for specific illustration.

For successful operation of a specific communications system, a design team or project with its own resources must seek, sort, and integrate existing scientific information plus identify and conduct necessary research on key unknowns. When delineated systems contend for or are forced to share spectrum in overlapping areas of application, the information development, analysis and sharing methodology has followed a detailed project approach by the contending parties. In many cases, areas lacking scientific knowledge are found which generate (1) some relevant R&D, (2) overly conservative criteria, and (3) inhibition of system implementation. The results of such specialized efforts tend to be limited in scope. The relevant technical issues may be less general than desirable and the research effort tends to terminate when system spectrum contenders settle their differences. An open question exists as to whether a more general context can be found (established) with a meaningful scientific structure which generates technical interaction (propagators, communicators, systems operators, policy makers) in order to evolve new system sharing methodology, efficient data collection, aggregation and dissemination, measurement techniques, and performance criteria.

VI. 4-2 SPECTRUM SHARING IN AERONAUTICAL RADIONAVIGATION - A LOOK AHEAD.* Irvin G. Stiglitz, MIT Lincoln Laboratory, Lexington, Massachusetts

The demand for channel allocations for Air Traffic Control (ATC) functions will continue to press on the available spectrum. Modifications within existing

*This work has been supported by the Transportation Systems Center, Department of Transportation, Cambridge, Massachusetts.

allocations will provide means of satisfying the demand. For example, the VHF voice link channels are scheduled to be compressed from today's 50 kHz to 25 kHz. A similar reduction (100 kHz to 50 kHz) is planned for the VHG Omni Ranging (VOR) channels.

Three new systems are planned for implementation during the 70's. The Microwave Landing System (MLS) is to operate at SHF and will employ spread spectrum techniques for sharing of the DME (Distance Measuring Equipment) channels and frequency division multiple access along with geographic separation for sharing of the angle measuring channels.

The Discrete Address Beacon System (DABS) is being designed to share the same channel with today's Air Traffic Control Radar Beacon System (ATCRBS). Careful design of signaling waveforms and coding for DABS will provide the required protection against interference.

Initial deployment of satellites for ATC has been planned for introduction during this decade. Communication and surveillance will be provided for the North Atlantic by Aerosat. Aerosat will employ both VHF and L-band. Aerosat will also serve as a vehicle for assessing the role of satellites over the Continental United States.

VI. 4-3 IMPACT OF CHANNEL CODING ON SPECTRAL SHARING. Irwin Mark Jacobs, Linkabit Corporation

Convolutional encoding with Viterbi and/or feedback decoding is being applied to certain digital satellite communications systems. In Gaussian noise, such techniques yield coding gains of 4-5 dB for bit error rates of 10^{-5}. These gains are robust and are often greater in practice than theory, due to the reduced signal-to-noise ratios required in modem and transceiver.

Binary coding has obvious implications for spectral sharing, since rate-1/2 coding doubles the required bandwidth and rate-3/4 coding increases it by 1/3. (Tradeoff of bandwidth for signal-to-noise ratio is of course also used in present FM systems.) A compensating factor is the reduction in required power levels in the widened signals, 6.2 dB or more for rate 3/4, which reduces the interfering properties of the signal. A second factor is the improved capability of the coded signal to withstand interfering signals and signal-dependent noise produced by nonlinearities and linear filtering effects, thereby allowing less frequency guard space in frequency division multiple access (FDMA) systems and more simultaneous users in code division multiple access (CDMA) systems. Coding also reduces the bandspreading required for combatting multipath. Theoretical and simulated results will be presented.

VI. 4-4 RANDOM ACCESS DIGITAL COMMUNICATION FOR A CELLULAR SYSTEM. L. Schiff, RCA Laboratories, Princeton, New Jersey

A random access digital multiplex system of the same type as the Aloha [1, 2] system is considered. The terminals using this system are imbedded in a cellular [3, 4] radio system. All communications is destined for a single source - a central processing unit to which all cellular transceivers are connected.

The number of cells in the system is sufficiently large and the transmit power used by terminals and cellular transmitters sufficiently small so that terminals sufficiently far apart can simultaneously transmit without mutual interference. However, since the transmit power must be sufficiently large for reliable communication, it is clear that transmissions do reach into adjacent cells and mutual interference will occur for terminals in cells that are close enough to one another. In other words, if there are N cells, the problem cannot be simply treated as N isolated sub-systems. This ultimately limits the amount of spectral reuse it is possible to achieve.

Within these constraints it is possible to organize the system in different ways in order to achieve the most efficient operation with a given amount of mutual overlap or interference. Efficiency is measured by the traffic volume handled per cell per channel for a given probability of message rejection.

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2. W. H. Bortels, "Simulation of Interference Packets in the Aloha System," Aloha System Tech. Rep. B70-2, University of Hawaii, March 1970.
3. L. Schiff, "Traffic Capacity of Three Types of Common User Mobile Radio Communications Systems," IEEE Trans. on Comm. Tech., COM-18, No. 1, Feb. 1970, pp. 12-21.
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VI. 4-5 EFFICIENT USE OF THE MOBILE RADIO SPECTRUM. D. C. Cox and D. O. Reudink, Bell Telephone Laboratories, Incorporated, Crawford Hill Laboratory, Holmdel, New Jersey 07733

Large scale mobile radio systems can make efficient use of the radio spectrum if radio coverage is limited to small areas surrounding base stations and radio channels are reused in areas separated far enough apart to insure that cochannel interference is at an acceptably low level. Spectral efficiency can be further increased by using dynamic channel assignment and reassignment techniques [1] to increase the average channel occupancy. These techniques adapt the number of channels available in each coverage area to better match the instantaneous and random peaking of demand from area to area which occurs in such systems. The dynamic channel assignment and reassignment algorithms must maximize the channel reuse within the cochannel interference constraint and simultaneously provide the flexibility required to serve the demand peaks. This paper presents examples of such algorithms and examples of the resulting improvement in channel occupancy. The results were obtained by computer simulation of systems with one- and two-dimensional coverage area layouts. As an example, a system with 160 duplex radio channels reuseable every 4th coverage area and using dynamic channel assignment and reassignment to work against a uniform spatial demand produces an average channel occupancy (.77) at 1% blocking which is 75% greater than the occupancy (.44) of a similar system which fixes the allocation of the channels at 10 per coverage area (10 channels x 16 separate areas = 160 channels).

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RADAR SIGNAL PROCESSING TECHNIQUES

A. A. Ksienski, Chairman

VI. 5-1 PARAMETER-ESTIMATION OF MULTIPLE-SIGNALS. Raymond Anton Birgenheier, Hughes Aircraft Company, Culver City, California

The problem of parameter-estimation of multiple-signals is investigated, in which the effect of the parameter of a particular signal is to produce a constant phase change from sample to sample of the signal. This type of parameter is found, for example, in direction-finding or frequency-estimation of signals. Noise is added to each sample of the signals so that a set of M samples and additive noise comprise an M-dimensional vector, $\underline{y}$. There are N-signals with independent coefficients which are either assumed to be complex Gaussian random-variables, or are assumed to have no *a priori* statistics. From the likelihood function, a sufficient statistic is obtained which is a quadratic function of the observable-vector, $\underline{y}$, and a nonlinear, multimodal function of the unknown N-dimensional parameter-vector, $\underline{x}$. For the single-signal case, the sufficient statistic is a discrete-Fourier transform of $\underline{y}$ which is used in conventional estimation - even of parameters of multiple-signals.

To obtain the maximum-likelihood estimate of the parameter vector, the sufficient-statistic is maximized with respect to the vector $\underline{x}$. The statistic is expanded in a form that lends itself to maximization by a new sequential search algorithm. The salient feature of the algorithm is that the N-dimensional global search for the maximization of the sufficient statistic is reduced to a sequence of relatively few 1-dimensional global searches. It is shown, theoretically, that the algorithm results in convergence to a local maximum of the statistic.

The results of computer-simulations are presented in which the dimension of the observable is equal to 8 and in which 2 to 5 signals are present. From the simulations, it is found that, except for unusually difficult cases, such as when there are several signals with parameters that differ by less than the resolution of a conventional estimator, the algorithm results in the location of the global maximum of the sufficient statistic. It is found that by the utilization of the algorithm, the global maximum of the statistic is located rapidly, and that the performance of the estimator in which the algorithm is employed is superior to the performance of a conventional estimator.

An attractive feature of the algorithm is that a test can be incorporated readily for the estimation of the number of parameters. The results of simulations are presented in which this test is utilized, and it is found that the test is effective, and even facillitates the estimation by eliminating a dimension in the search when two signals are essentially unresolvable.

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VI. 5-2 ANGLE TRACKING OF NARROWLY SPACED TARGETS. J. E. Howard, Hughes Aircraft Company, Culver City, California

The accuracy of radar angle tracking is normally limited by antenna beamwidth when multiple targets are being tracked. This property is a consequence of the way the wavefronts from multiple target returns mutually interfere at the antenna. It is possible to accurately track the multiple targets, however, if the signals measured at multiple points along an aperture are separately brought to a signal processor and analyzed.

Performance curves that show the angle-tracking error as a function of radar parameters are presented. The curves were generated from experimental data as well as computer simulation. The effects of thermal noise, target separation, and target reflection characteristics on angle error are shown. The results demonstrate a practical capability for two-target tracking for targets spaced as narrowly as 1/4 beamwidth apart. The experimental equipment was designed to interface with an X-band tracking radar. The equipment has been tested against beacons, confirming the simulated results. An analysis of the effect of multi-pulse smoothing and processing speed advancements on the tracking performance is included to indicate the engineering tradeoffs that are available in the design of a multiple target tracker.

VI. 5-3 A NOVEL AIRBORNE RADAR TECHNIQUE FOR MOVING TARGET DETECTION, LOCATION AND TRACKING. John K. Schindler, W. B. Goggins, Jr., Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, MA

A novel radar technique for detecting, locating, and tracking moving targets from an airborne platform is described and analyzed. The technique utilizes the fact that during an extended observation time moving targets present a linear doppler frequency modulated (fm) signal which, with some exceptions, is quite dissimilar to the linear doppler f.m. signals of stationary ground clutter. The exceptional cases where clutter and moving targets present identical doppler spectra are defined. The doppler-doppler rate resolution and ambiguity properties of linear processors designed to detect moving targets against white noise and clutter are analyzed. The processor properties permit estimation of target sub-clutter visibility as a function of target location and velocity, antenna characteristics, radar pulse repetition frequency (prf) and the number of pulses coherently integrated. Typical results for a sixty-four pulse processor employing a wide angle surveillance antenna at the minimum unambiguous clutter prf yields between 16 and 32 dB sub-clutter visibility depending upon target velocity. Several digital realizations of an AMTI processor are being examined from the viewpoint of computational efficiency. Finally, phase monopulse techniques can be implemented with the output from a second delayed synthetic aperture to provide target angular position. It appears that this angular position data together with target mean doppler frequency and rate of change of doppler frequency can provide moving target ground speed and true heading.

VI. 5-4 COMPUTER MODELLING OF CLUTTER FOR COHERENT MTI RADAR.
C. D. Hawkes and S. S. Haykin, McMaster University, Canada

This paper describes the analysis and simulation of the video signal obtained when a coherent pulse radar scans through scintillating, moving scatterers. The overall objective is to produce a computer model that may be used to study an adaptive filtering scheme for MTI processors. For this study it is necessary to be able to generate data that corresponds to a given set of physical conditions, and whose characteristics are well defined.

In the analysis of the video signal, a formula for the complex autocorrelation of the clutter signal has been obtained. This formula extends previous formulas, and can take account of the signal transmitted and the matched filter used at the front end of the radar. The computer model is simple and uses readily available random number generators. Good agreement is shown between the theoretical formula and the measured autocorrelation of the data generated on the computer. A typical timing is 150 seconds for 5000 complex points on a CDC 6400 computer. The wide range of clutter characteristics that can be generated by this model make it not only suitable for the study of MTI, but also suitable for any simulation of clutter, whether for a coherent or non-coherent radar.

VI. 5-5 FREQUENCY AGILITY TO REDUCE RADAR MULTIPATH ANGULAR POINTING ERRORS.
D. G. Burks, H. V. Poor, Z. L. Burrell and E. R. Graf, Department of Electrical Engineering, Auburn University, Auburn, Alabama, 36830

Frequency agility, pulse to pulse variation of radar transmit frequency, has been used to obtain improved tracking performance in several situations. The best known of these are increased probability of detection [1] and reduction of glint pointing errors [1-3]. Both of these effects are the result of the radar cross-section of the target being a strong function of frequency, usually because the target is effectively an ensemble of scatterers separated by several wavelengths.

In addition to the above benefits of frequency agility, it has been reported [1] that frequency agility is useful in the reduction of angular pointing errors due to multipath propagation. A simulation of a microwave radar propagation setting including ground reflection multipath has been made in order to determine the mechanism of multipath pointing error reduction by frequency agility and to obtain estimates of the expected error reduction.

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The targets of interest in this study were small aircraft at short range and low elevation. The radar cross-section describes the scattering properties of the target. In order to obtain a simple deterministic radar cross-section, the target is modeled [4] by a collection of perfectly conducting ellipsoids arranged in the shape of a small jet aircraft, see Figure 1. Each ellipsoid in the model contributes to the radar cross-section by specular reflection of the incident wave. The total target cross-section is then found by coherent summation of the scatter from individual ellipsoids.

Since multipath is caused by scatter from the target to the ground and back to the antenna (or in the reverse direction) the cross-section of the target must be known for given incident angles and generally different scatter angles. This bistatic cross-section is found by the same procedure of coherent summation of scatter of individual target components. Also taken into consideration is illumination shadowing of any target component obscured by another target component. The monostatic RCS in the azimuth plane is shown in Figure 2.

Reflection of energy from ground scatterers completes the multipath propagation loop. Several terrain scatter models have been proposed [5]. Probably the simplest of these is an infinite conducting plane. The plane will reflect incident waves in the specular direction and the apparent source of the ground reflection will be from the image of the target located symmetrically below the surface [Figure 3]. The planar surface is a poor model for terrain around most radar sites due to the irregular features of that surface.

A rough surface scattering model is chosen as a more practical representation of the scatter from the terrain about the antenna. As a planar surface is slightly roughened, scatter energy is removed from the specular direction and distributed about that direction. The amount of dispersion of this scatter about the specular direction is related to the rms surface roughness and the correlation of the surface height distribution over the plane [5]. Also with the increase in rms surface roughness is a transition from coherent scatter, or the vector summation of scatter over the surface, to incoherent scatter, or the summation of scattered power over the surface. This is due to the large number of specular points on a very rough surface.

Characteristics of the radar system which most effect multipath errors are the antenna pattern, height of antenna, angle error determining system and to some extent range gate width. In our simulation a 5.5 GHz radar with linear phased array antennas are of interest. The radar is frequency agile over a bandwidth of approximately 500 MHz.

The paper will discuss the effects of surface roughness on expected angle error reduction when frequency agility is used. Also discussed is the frequency selection sequence and signal processing based on the amplitude of returns at different selected frequencies.

VI. 5-6 DIGITAL INTERPOLATION FOR REDUCING STRADDLING AND GRANULARITY LOSSES. Harry Urkowitz, Richard P. Perry, and Leonard Weinberg, RCA Missile and Surface Radar Division, Moorestown, N.J. 08057

In digital systems, limited sampling rate (granularity of sampling) may cause a waveform's maximum to be straddled, leading to a straddling loss. This loss may be reduced by interpolation. Interpolation, in digital processing, means fitting a continuous curve to a set of sample values of a waveform and then deducing certain properties of the original waveform from the properties of the fitted curve. The value and position of a maximum are of particular interest. The type of interpolation curve considered is a collocation polynomial, that is, a polynomial passing through the known sample values. For parabolic interpolation, simple arithmetical operations upon three successvie sample values are required. In interpolating in radar angle (e.g., azimuth), the memory necessary covers the entire range interval stored by the radar. In some systems, a double loop sweep integrator is used to build up signal to noise ratio and the sweep integrator delays can serve double duty to provide, as well, the sample values for parabolic angle interpolation.

We also considered the fitting of a Gaussian curve to the sample values. With the addition of a logarithmic operation, Gaussian interpolation is the same as parabolic interpolation. Gaussian and parabolic interpolation were compared in a simulation of a matched filter receiver. The Gaussian interpolator was significantly more accurate both in locating a maximum and giving the value of the maximum.

Interpolation was applied to finding the position of a step transition in a digital system. An example of a step transition is the beginning or the end of the echo from an extended radar or sonar target. The position of the step transition is estimated by the position, on the interpolating curve, where the inflection point occurs.

VI. 5-7 MONOPULSE AZIMUTH ERROR DUE TO SELF-INTERFERENCE IN THE ATC BEACON RADAR ENVIRONMENT. B. Kulke, R. M. Weigand, and G. G. Haroules, U.S. Department of Transportation, Transportation System Center

Measured data are presented that describe the angle error of monopulse direction finding in the ATC radar beacon system, due to interference either from multipath or from overlapping replies that are generated by neighboring targets. At the same time, the data serve to validate an existing analytical model for coherent and incoherent interference.

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VI. 5-8 ADAPTIVE SPATIAL-TEMPORAL PROCESSING FOR AMTI RADAR.
R. S. Berkowitz, University of Pennsylvania

This paper is concerned with an assessment of adaptive processing techniques embodying independent control of antenna element weights on successive pulses for an airborne surveillance radar. While considerable improvement in rejection of mainlobe and sidelobe clutter echo contributions could be achieved by the use of optimum time-varying weights, severe difficulties are encountered in attempts to realize the real-time generation of such weights adaptively. Performance of a simple closed-loop estimation algorithm based on optimum steady state signal-to-noise ratio improvement is shown to be inadequate for clutter reduction purposes although it can perform admirably in the cancellation of spot jammer signals. The possibility of a pseudo-open-loop adaptive technique is examined and estimates are made of the potential of alternate schemes for realization of good estimates of the optimum weights.

VI. 5-9 SCANNING AND ELEMENT POSITION TOLERANCES IN ADAPTIVE ANTENNA ARRAYS OF ARBITRARY GEOMETRY. Bernard D. Steinberg and S. Hassan Taheri, Valley Forge Research Center, Moore School of Electrical Engineering, University of Pennsylvania

In a conventional antenna array, the location of each element should be known to an accuracy of about $\lambda/10$ for phasing and scanning purposes. A larger tolerance on the element location results in the loss of gain and deterioration of the radiation pattern.

In a self-cohering phased array, the phasing of the array elements is accomplished closed-loop and adaptively; therefore, no information on the element location is necessary. On the other hand, to scan the adaptively formed beam about the direction of the received wave, which has to be performed open-loop, one requires information on the element locations.

In this paper, basic relations pertaining to the open-loop scanning of adaptive antenna arrays of arbitrary geometry are derived for both far-field and near-field scanning problems, and the transition between the two cases and the required accuracies on the range of source are explored. It is further shown that the tolerance requirements on the element locations depends on the extent of scanning angle in azimuth and elevation. When the desired scanning is confined to a few tens of beamwidths of the array, it is shown that the tolerance on element location can be as much as two orders of magnitude larger than that in a conventional array.

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Session 6

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Rm 2

NUMERICAL METHODS I

E. K. Miller, Chairman

VI. 6-1 OPTIMIZATION OF RADAR CROSS SECTION OF N-PORT LOADED SCATTERERS. R. F. Harrington and J. R. Mautz, Syracuse University, Syracuse, New York 13210

A method is developed for reactively loading an N-port scatterer to maximize the radar cross section. The scattered field is first expressed in terms of the port characteristic modes of the body. If it is assumed that the scattering is due principally to one characteristic mode, the scattered field can be expressed as the ratio of two quadratic forms. This ratio is maximized subject to the constraint that the port current be real (or equiphasal). The resultant optimal port current is then resonated by reactive loads according to the modal resonance method. The theory can alternatively be developed in terms of port voltages. Because of the assumption that only a single mode contributes to the scattering, the results obtained using port currents may differ slightly from those using port voltages. When the scatterer is loss free and the loads are closely spaced, a large but very frequency sensitive cross section is obtained. This behavior is basically the same as that of supergain in antenna theory. A number of numerical examples are given for a wire object with four loaded ports. Computer programs are available to implement the theory for N-port wire scatterers of arbitrary configuration.

VI. 6-2 SOME COMPARATIVE NUMERICAL COMPUTATIONS ON WIRE SCATTERERS. C. M. Butler and D. R. Wilton, Department of Electrical Engineering, University of Mississippi, University, MS 38677

Numerous persons have reported findings of studies of thin wire antennas and scatterers, and, typically, such analyses are based upon numerical solutions of integral equations of either the Pocklington (E-field) or Hallen (magnetic vector/electric scalar potential) type. Various bases have been used for representation of the wire current, the unknown to be determined in either type integral equation. The particular basis set employed in a given case usually is selected to favor one, or a weighted combination, of the following: capacity to represent well the unknown current, amenability to attendant numerical calculations, and readiness of convergence to solution. In this paper is presented an investigation of the use of the two type equations mentioned above in conjunction with several bases selected to emphasis numerical solution efficiency. Deficiencies of these solution techniques/basis sets are delineated, and the claims of the authors are supported by voluminous data showing current distributions on straight- and L-wire scatterers. These deficiencies are discussed in detail and schemes for overcoming them are presented.

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VI. 6-3 USE OF DIFFERENCE EQUATIONS IN CONJUNCTION WITH MOMENT METHODS. D. R. Wilton and C. M. Butler, University of Mississippi, University, Mississippi, 38677

Pocklington's equation for thin wire antennas or scatterers is an integro-differential equation for the current. Under certain conditions the derivatives in Pocklington's equation can be analytically performed and moment methods used to calculate the current. Hallen's equation is also used in numerical work. If point-matching and subdomain current expansions are used the latter equation typically converges much more rapidly than the former, although it has the disadvantage of additional unknowns and constraints. If, alternatively, the derivatives in Pocklington's equation are replaced by the corresponding finite differences, an integro-difference equation results. Solution of the difference equation allows one to establish that with this procedure, the current solution asymptotically converges at the same rate as Hallen's equation but incorporating none of its disadvantages.

Another observation is the relation of the technique to using either triangle or piecewise sinusoidal testing functions with Pocklington's equation. When piecewise sinusoidal functions are used for both expansion and testing, functions in Pocklington's equation (i.e., Galerkin's method of piecewise sinusoidal reaction matching) an exact equivalence to the point-matched Hallen equation is noted.

Other uses of difference equations in conjunction with moment methods are also discussed. It is felt that difference equations provide a useful analytical tool and can give insight into many numerical techniques.

VI. 6-4 MOMENT SOLUTION FOR THE CURRENT AND IMPEDANCE OF COUPLED CYLINDRICAL ANTENNAS IN DISSIPATIVE MEDIA. A. W. Slisson and C. H. Ma, Department of Electrical Engineering, University of Mississippi, University, Mississippi 38677

The current distributions and input impedances of two identical, coupled cylindrical monopole and sleeve monopole antennas over a perfectly conducting ground plane within homogeneous isotropic media are investigated theoretically and experimentally. The antennas are assumed to be thin, linear, parallel and driven by delta-gap voltage sources. The Hallen-type integral equations are developed for the currents on the antennas with arbitrary excitations. The standard moment method is employed to solve the integral equations for two special cases. These are symmetric excitation with the two driving voltages identical and antisymmetric excitation with the two driving voltages equal in magnitude and 180° out of phase. A flat pulse basis set is used in the current expansion and point matching is applied at points along the antennas. Current distributions and input impedances of the antennas with the feed points located at the ground plane are obtained and compared with the theoretical and measured results of Mishra, Scott, and King. The effect on the current distribution of varying the location of the feed points and the space between the two antennas is also investigated. The measurements were performed with the antennas immersed in water and plasma at various values of conductivity and permittivity. A comparison among the theory, experiment, and some results of other authors gives good agreement.

VI. 6-5 ANTENNAS IN PROXIMITY TO GROUND--SOMMERFELD INTEGRAL EVALUATIONS. R. J. Lytle and D. L. Lager, Lawrence Livermore Laboratory

Sommerfeld integral evaluations occur in exact integral equation expressions for the current on antennas above, below, and penetrating through the ground-air interface. Approximate evaluations of these integrals are feasible in some situations, however many situations require a numerical evaluation of these integrals. For example, antennas in close proximity to ground and which extend over a wavelength or more require accurate and rapidly convergent evaluations of these integrals. The effect of the contour of integration upon the convergence rate has been studied for various source/receiver locations, frequencies, and ground parameters. The effect of the branch cut locations and approximate evaluations of the integrals in the "singular" region is discussed. Those regions where approximate evaluations (e.g., reflection coefficient and ground wave approximation) are sufficiently accurate are mentioned. Numerical results are presented for antennas penetrating through the ground-air interface.

VI. 6-6 A SPHERE OF INFLUENCE ITERATION TECHNIQUE FOR ELECTROMAGNETIC SCATTERING PROBLEMS.* V. P. Cable, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering

A linear iteration scheme called Sphere of Influence (SOI) is introduced and investigated as the principal numerical technique used in conjunction with moment methods to solve electromagnetic scattering problems. The basic SOI method takes advantage of diagonal predominance in the (impedance) coefficient matrix produced by the moment method and uses a coupling criterion in computing a unique set of iteration matrices.

Convergence properties of the SOI method are studied for the cases of scattering from large (>100 elements) random arrays of discrete thin wire elements,

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*The work reported in this paper was supported in part by Contract F33615-72-C-1435 between Air Force Avionics Laboratory, Wright-Patterson Air Force Base, Ohio, and The Ohio State University Research Foundation.

from a wire grid model of a solid body and from a surface patch representation of a corner reflector. The nature and condition of the coefficient matrix is investigated in light of the various computing models used and basic advantages and limitations on use of the SOI method are summarized.

The SOI technique is compared to other well known iterative techniques, including one non-linear method, and preliminary results indicate SOI is a competitive candidate for scattering problems too large for direct solution.

VI. 6-7 SURFACE WAVES ALONG WIRE MESHES. K. C. Chen, Air Force Weapons Lab, Kirtland AFB, N.M.

Based on the averaging boundary conditions of Kontorovich for $r_{\cdot}/a \ll 1$, and $a/\lambda \ll 1$, where $r_{\cdot}$ is the wire radius, a is the mesh size, it is found that the surface waves along the mesh wire attenuate quite fast away from the mesh plane, and propagate slower than the velocity of light.

A limiting case of a system of parallel wires is studied. It turns out that Kontorovich's condition is not directly applicable.

Launching efficiency of a dipole above the mesh plane, the propagation constants along the mesh plane, and the attenuation constants perpendicular to the mesh plane are computed for various cases.

Transmission line approach through the calculation of L and C is also made.

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Session 8 — Rm 1

DIFFRACTION AND SCATTERING

T. B. A. Senior, University of Michigan, Chairman

VI. 8-1 SCATTERING OF ELECTROMAGNETIC SHORT PULSES FROM UNDULATING CONDUCTING SURFACES. G. C. Georges, Naval Research Laboratory, Washington, D.C. 20375

A new method is being explored for investigating the scattering of electromagnetic waves from undulating conducting surfaces. This method involves the analysis of electromagnetic scattering of an impulse excitation. An iterative scheme is employed to obtain a self-consistent solution for the induced surface currents. For the transient excitation that we consider, the currents are found to be highly localized disturbances which radiate (in a manner analogous to Cerenkov radiation) as they travel along the scattering surface. This formulation results in a dynamical picture of the scattering process in terms of a collection of localized surface currents (or quasi-particles) whose evolution depends on the nature of the excitation and undulations of the scattering surface.

Examples of this method are presented for various deterministic forms of the scattering surface and a consideration is made of extending the work to random scattering surfaces.

VI. 8-2 A HIGH-FREQUENCY SCATTERING MODEL BASED ON THE SHORT PULSE RESPONSE. Hitoshi Inada, University of Illinois at Chicago Circle

Short pulse backscattering associated with surface waves on a dielectric sphere is investigated in the time domain. Construction of a scattering model is not easy in the frequency domain, but could be easier in the time domain due to time delays of short pulses. Using separately computed numerical values of the amplitude and phase of CW approximate solutions [1] for surface waves, short pulses of electromagnetic waves are synthesized economically by using the Fast Fourier Transform algorithm. Ray and Stephens [2] have considered short pulse responses of ice spheres with refractive index 1.78 - i0.0008, using a surface wave of one cut and geometrical optics field contributions. It has been reported that effective transient decay time is less than a space-equivalent time of 6 diameters. However, with higher-order surface waves [1] of multiple cuts, effective decay time will be shown approximately a space-equivalent time of 80 diameters. In general, short pulse responses for surface waves on dielectric spheres demonstrate vividly the presence of a series of surface wave returns. Amplitudes and time delays of the short pulse returns are compared with those [3] obtained using the Mie solution. An excellent agreement was obtained. Individual short pulse returns can now be identified with the help of van de Hulst's scattering model using a slightly modified path. It is shown that significant pulse returns of surface waves for the backscattering come from the surface waves which have made the maximum number of short cuts possible through the sphere.

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VI. 8-3 EXACT SOLUTION FOR THE SCATTERING OF CYLINDRICAL BEAM RADIATION FIELDS BY SPHERICAL OBJECTS. R. J. Pogorzelski, University of Mississippi, University, Mississippi, and E. Lun, University of California, Los Angeles, California

We obtain the expansion of nonsingular vector cylindrical harmonics in terms of vector spherical harmonics and make use of this series expansion in analyzing the scattering of a beam type radiation field by a homogeneous dielectric sphere. That is, we represent the beam in terms of vector cylindrical harmonics by means of the Hankel transform and use the series expansion to reexpress the field in terms of vector spherical harmonics which are then treated individually as to their scattering from the sphere surface. (Were the incident radiation a plane wave, this procedure would lead to the well known Mie series.) We emphasize that this formulation is exact and, as such, is not limited as to sphere size nor beam diameters. (However, it is noted that at present the series expansion is limited to nonsingular incident fields.) Numerical results for several cases are presented.

VI. 8-4 SYNCHROTRON-DIFFRACTION RADIATION SPECTRA IN THE PRESENCE OF A PENETRABLE SPHERE. R. J. Pogorzelski* and C. Yeh, University of California, Los Angeles, California 90024

Most previous studies of diffraction radiation [1-3] were carried out for perfectly conducting (impenetrable) bodies such as, conducting half planes, screens, or gratings, open ends of metallic waveguides, or conducting spheres [4]. Very little work has been carried out for the case of penetrable (dielectric) bodies [5]. This paper deals with the case of a charged particle orbiting concentrically around a dielectric sphere. Due to resonance and diffraction phenomena, the radiation characteristics for this configuration are expected to be significantly different from those of ordinary synchrotron radiation. It should be noted that since a fundamental feature of diffraction radiation is that the sources excite a spectrum of frequencies, it is essential that exact solutions (valid for all frequencies) be obtained.

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We formulate the problem by representing the current equivalent to the moving charge in terms of its temporal Fourier transform, i.e.,

$$\vec{J}_\omega = \frac{q}{r_o} \delta(r-r_o)\delta(\cos\theta)e^{i\frac{\omega}{\Omega}t} \hat{a}_\varphi$$

where q is the charge, r_o is the radius of the orbit, and Ω is the angular velocity of the particle. Thus we reduce the problem to solution of the vector wave equation,

$$\nabla\times\nabla\times\vec{E}_\omega - \omega^2\mu_o\epsilon\vec{E}_\omega = i\omega\mu_o\vec{J}_\omega$$

where ϵ is ϵ_o outside the sphere, $r>a$, and ϵ_1 inside, $r<a$, and $\vec{E}_\omega$ is the Fourier spectrum of the electric field intensity $\vec{E}$. This equation is solved by means of the appropriate dyadic Green's function [6]. The Green's function satisfies,

$$\nabla\times\nabla\times\overleftrightarrow{G}(\vec{r}|\vec{r}\,') - \omega^2\mu_o\epsilon\,\overleftrightarrow{G}(\vec{r}|\vec{r}\,') = \overleftrightarrow{I}\delta(\vec{r}-\vec{r}\,')$$

where $\overleftrightarrow{I}$ is the unit dyadic. It follows then that,

$$\vec{E}_\omega(\vec{r}) = i\omega\mu_o\int_{V'}\overleftrightarrow{G}(\vec{r}|\vec{r}\,')\cdot\vec{J}_\omega(\vec{r}\,')dv'$$

We express the Green's function, and hence the electric field and the radiated power, as a sum of vector spherical harmonics of order ℓm. Then by performing (numerically) the sum on ℓ from m to ∞ for each m, we obtain the power radiated into each harmonic $m\Omega$, i.e., we obtain the power spectrum of the radiation.

The power spectra are plotted for fixed orbit radius over a range of sphere sizes. We note that the resonances of the sphere are clearly discernable and become more pronounced as the sphere surface approaches the moving particle. The spectra are also plotted for fixed sphere size over a range of orbit radii to show how the strength of the interaction varies with the proximity of the particle to the surface. When the particle orbits close to or inside the sphere the resonance phenomenon is most pronounced and, at resonance, one term of the expansion on ℓ for the resonant harmonic m predominates and the radiation at $\omega=m\Omega$ is radiated for the most part (in some cases almost entirely) into a single spherical harmonic. In the absence of a resonance effect the dominant ℓ value is $\ell=m$ and in many cases the resonance is not strong enough to change this fact.

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VI. 8-5 SCATTERING BY A MULTILAYERED DIELECTRIC-COATED CONDUCTING CYLINDER. T. C. K. Rao and M. A. K. Hamid, Antenna Laboratory, Department of Electrical Engineering, University of Manitoba, Winnipeg, Canada R3T 2N2

The scattering cross-section of a multi-layered homogeneous dielectric-coated conducting cylinder is derived by employing the boundary value method, when a plane wave is incident at any arbitrary angle. Attempt has been made to optimize the radial dielectric profile for either minimum or maximum back-scattering cross-section. In addition, the effect on the cross-section of a small wall air gap surrounding the conducting cylinder is investigated and the relative contributions of the geometrical optics and creeping rays excited in the structure are discussed from an asymptotic expansion of the eigenfunction solution.

VI. 8-6 EXTENDED BOUNDARY CONDITION INTEGRAL EQUATIONS FOR PERFECTLY CONDUCTING AND DIELECTRIC BODIES: FORMULATION AND UNIQUENESS.* K. A. Al-Badwaihy and J. L. Yen, Department of Electrical Engineering, University of Toronto, Toronto, Ontario, Canada

Introduction. For scattering by a perfectly conducting body, the electromagnetic field is known to satisfy the generalized boundary condition (g.b.c.) whereby the field vanishes everywhere inside the scatterer. Because of analytic continuability of solutions of partial differential equations of elliptic type, Waterman [1] showed that if the field vanishes in any portion of the interior, then it satisfies the g.b.c. This is referred to as Waterman's extended boundary condition (e.b.c.).

So far the g.b.c. and the e.b.c. have only been applied to perfectly conducting bodies. A novel method for deriving g.b.c. integral equations for dielectric and multiple composite scatterers is presented in this paper. The formulation applies to a finite number of bodies with linear constitutive parameters embedded in an infinite linear host medium. An arbitrary spatial distribution of impressed sources is allowed everywhere in space.

The e.b.c. concept is generalized in this paper and is redefined as the requirement that a set of observables vanishes over an observation domain in the

*This work was supported by the National Research Council of Canada under Grant A-3951.

zero field region. It is shown that the solution is unique if the observation domain is restricted to a closed surface, a portion of a plane or a portion of a straight line, all completely in the zero field region, provided the proper observables vanish in each case. The integral equations satisfying the e.b.c. have regular kernels that are easy to evaluate.

Formulation and Uniqueness of Generalized Boundary Condition Integral Equations. We proceed to derive g.b.c. integral equations for a scattering problem using the equivalence theorem [2]. The unknown functions are the components of the electric and magnetic fields tangential to the interfaces between different media. The number of equations is twice the number of interfaces between dielectrics plus the number of interfaces between perfect conductors and dielectrics. This is a consequence of the fact that the tangential electric field vanishes on the bounding surface of a perfect conductor. The dielectric bodies may be lossy or lossless.

Single Scatterer. Figure 1a shows a homogeneous body with linear constitutive parameters (ε_1,μ_1) and impressed sources $(\vec{J}_1,\vec{M}_1)$ bounded by a closed surface S and embedded in an infinite homogeneous host medium (ε_o,μ_o) with impressed sources $(\vec{J}_o,\vec{M}_o)$. It is required to find the tangential components of the electric and magnetic fields on S. Once these components are known, the evaluation of the field everywhere is straightforward.

From the equivalence theorem, the field outside S can be maintained by surface currents $\vec{j}_1=\vec{n}\times\vec{H}$ and $\vec{m}_1=\vec{E}\times\vec{n}$ on S, where $\vec{E}$ and $\vec{H}$ are the electric and magnetic fields on S respectively and $\vec{n}$ along the outward normal. As shown in Fig. 1b these currents together with the external sources produce the same exterior field as the original problem but zero field in V which can now be assumed filled with the host medium. Since the currents are now radiating in a homogeneous unbounded space, the field everywhere can be simply obtained using the surface currents $(-\vec{j}_1,-\vec{m}_1)$ along with $(\vec{J}_1,\vec{M}_1)$ radiating in a homogeneous unbounded space of constitutive parameters (ε_1,μ_1) produce the same interior field as the original problem but zero field outside S, as is shown in Fig. 1c. We have thus derived two "component" scattering problems from the original problem, each of which involves a single medium. The conditions that the fields vanish in the appropriate regions in the component problems constitute the g.b.c. for the original problem. The two g.b.c. coupled integral equations for $(\vec{j}_1,\vec{m}_1)$, whose solution is unique [3], can be easily written by imposing the zero field conditions in Figs. 1b and 1c. The above procedure can be easily applied to multiple composite scatterers.

Extended Boundary Condition Integral Equations. Extended boundary condition integral equations are obtained by restricting the observation point to a subdomain in the zero field region. Particular choices of the observation domain are considered here; these include a closed surface, a plane portion or a line portion in the zero field region. Uniqueness is guaranteed if the proper observables vanish in each case.

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Let the closed surface S divide the space into two regions V_i and V_o inside and outside S respectively as is shown in Fig. 2. Let us adopt the following definitions where the choice of the Z axis is arbitrary and V stands for the zero field region.

Definitions

(i) A generalized boundary condition is that all field components vanish for all points in V.
(ii) A standard boundary condition is that the component of the electric field tangential to S vanishes for all points on S.
(iii) An extended boundary condition is that some observables vanish for an arbitrary observation domain in V.

Out of the extended boundary condition let us define the following:

(a) Waterman's e.b.c. is that two scalars defining the electromagnetic field vanish for all points in a subvolume $V' \epsilon V$.
(b) Closed surface e.b.c. is that either the tangential component of the electric or the magnetic field or both, or a combination of both, vanish over a closed surface S' in V. S' may coincide with S in a limiting process.
(c) Plane e.b.c. is that $E_z = H_z = \frac{\partial E_z}{\partial z} = \frac{\partial H_z}{\partial z} = 0$ for all points on a portion of the XY plane totally contained in V.
(d) Line e.b.c. or axis boundary condition (a.b.c.) is that

$$\int_0^{2\pi} \left(\frac{\partial}{\partial \rho}\right)^n \begin{pmatrix} E_z \\ H_z \end{pmatrix} \begin{pmatrix} \cos n\varphi \\ \sin n\varphi \end{pmatrix} d\varphi = 0 \quad ; \quad \rho = 0, n\epsilon[0,\infty]$$

for all points on a portion of the Z axis contained in V and (ρ,φ,z) is a cylindrical coordinate system.

Uniqueness. The standard boundary condition (ii) does not guarantee that the field vanishes everywhere in V for values of the wave number k for which internal resonances exist in V and hence is not unique for all values of k [1]. Waterman's e.b.c. is unique independently of whether or not resonant modes can exist in the interior [1]. The other choices of the e.b.c. are unique and details of the uniqueness are given in [3]. For the closed surface type, the following remarks are made:

(i) Interior problem. The solution is unique if either $\vec{E}_t$ or $\vec{H}_t$ vanishes over the surface S_o'.
(ii) Exterior problem. The solution is not unique if either $\vec{E}_t$ or $\vec{H}_t$ vanishes over S_i' but is unique if both $\vec{E}_t$ and $\vec{H}_t$ vanish on S_i'. It is desirable, however, to reduce the two conditions $\vec{E}_t = \vec{H}_t = \underline{0}$ to one condition, possibly including a combination of both $\vec{E}_t$ and $\vec{H}_t$ so as to avoid overdeterminacy in the resulting integral equations. It is found [3] that the solution is also unique if

$$(\alpha\vec{E}_t + \vec{n}\times\vec{H}_t) = 0 \quad \text{over } S_i'$$

where α can be arbitrarily specified over S_i' and Re $\{\alpha\} \neq 0$. If S_i' is allowed to coincide with S we get a combined electric and magnetic field integral equation. The interesting fact is that this linear combination of the electric and magnetic field integral equation always has a unique solution even though the individual equations may not have unique solutions.

Conclusions. Integral equations of the generalized boundary condition are derived for multiple composite scatterers. The formulation applies to perfectly conducting, lossless or lossy dielectric scatterers. The extended boundary condition concept (e.b.c.) is generalized in this paper and particular choices of the e.b.c. equivalent to the g.b.c. are given. A combined electric and magnetic field integral equation whose solution is always unique is also derived.

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Fig. 1. Single scatterer and generalized boundary condition component problems.
Fig. 2. Extended boundary condition for interior and exterior problems.

VI. 8-7 DIFFRACTION FROM OPEN SHELLS. K. M. Mitzner, Northrop Corporation, Aircraft Division, Hawthorne, California

The high frequency backscatter from an open convex shell S bounded by an edge C can be represented as the sum of a physical optics scattering integral over S plus the line integral around C of a fringe wave diffraction coefficient. It is shown here that the physical optics integral can be approximated accurately by a line integral around C plus a specular point contribution (if there is a specular point on S), provided that any specular point on S or "ghost" specular point on the mathematical continuation of S is sufficiently far from C. The two line integrals can then be summed to yield an expression for the total edge diffraction as the integral around C of a diffraction coefficient. This diffraction coefficient cannot be derived correctly from two-dimensional canonical problems.

Various ways of evaluating the integral are discussed. In the simplest case, with C smooth and rapid phase variation along C, stationary phase evaluation yields the standard Geometrical Theory of Diffraction result.

The approach used here is not merely a generalization of flat plate theory. Indeed, the criterion for replacing the surface integral by a line integral is not satisfied for almost-flat surfaces at near-normal incidence.

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Session 10 Room 1

MEDIA EFFECTS ON WAVE TRANSMISSION

A. Ishimaru, Chairman

VI. 10-1 MILLIMETER AND OPTICAL PULSE PROPAGATION THROUGH A RANDOM DISTRIBUTION OF PARTICLES. Akira Ishimaru and S-T Hong, Dept. of Electrical Engineering, University of Washington, Seattle, Washington 98195

This paper presents a study on the propagation characteristics of a millimeter and an optical pulse through random distribution of moving particles. Examples are rain, fog and cloud particles. Formulations are based on the extension of the Foldy-Twersky integral equations to include the two-frequency correlation functions and motions of the particles. Three cases considered are plane wave incidence, spherical wave taking into account transmitting and receiving patterns, and beam wave. Two-frequency correlation junction, coherence time and coherence bandwidth have been obtained and numerical examples are shown for the carrier frequencies of 40 and 100 GHz with bandwidth up to a few GHz and a short nanosecond optical pulse. It is shown that for millimeter waves, the coherence time and bandwidth strongly depend on the transmitting and receiving patterns, and that the coherence time and bandwidth are smaller for a plane wave incidence than for a narrow-beam spherical wave. The coherent intensity of a pulse attenuates but its spread in time is small. The incoherent intensity of a pulse increases significantly with distance and its spread in time can be many times the transmitting pulse width due to multiple scattering effect.

VI. 10-2 STATISTICS OF THE FIELD INSIDE A SLAB OF ONE-DIMENSIONAL RANDOM MEDIA BY THE MARKOV APPROXIMATION. Roger H. Lang, George Washington University, Washington, D.C.

Recently [1] the mean field and intensity were calculated inside a slab of one-dimensional random medium in the parameter range where the slab is strongly backscattering. These results were found by employing the method of invariant imbedding to convert the boundary value problem to an initial value problem. The refractive index variations were then chosen to be a particular Markov process, and two cascaded diffusion equations were obtained for the probability density function of the reflection coefficient and the field in the slab.

We now extend these results to a slab which has arbitrary index fluctuations. To do this, we use Stratonovich's result which states that an arbitrary random process approaches a Markov process in a certain limiting sense. The results show, as in the specialized case, that thick slabs backscatter almost all of the incident energy when $k\ell \sim O(1)$ where k is the free space wavenumber and ℓ is the correlation length of the medium fluctuations. Following this, the methods employed above are used to explore the relationship between the forward and backscattering regimes.

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VI. 10-3 POSITION-DEPENDENT CHARACTERISTIC IMPEDANCE OF INHOMOGENEOUS LOSSY MEDIA. Dr. H. E. Foster, Rockwell International, Autonetics Division, Anaheim, CA and Dr. Chen-To Tai, Radiation Laboratory, University of Michigan, Ann Arbor, MI

Plane wave propagation in media whose series attenuation varies solely with position in the direction of propagation may be characterized by a position-dependent characteristic impedance. The characteristic impedances encountered in such media are different for oppositely directed propagating waves. Expressions for these impedances can be derived by applying some principles of invariant imbedding to parametric descriptions of infinitesimal cells in the media. A general expression for the position dependent bilateral characteristic impedance is derived for any general non-uniform resistance distribution in the medium. In the special case of a constant resistance distribution the expression is shown to reduce to the known result.

VI. 10-4 FINITE DIFFERENCE METHODS FOR TIME DOMAIN ELECTROMAGNETIC PULSE PROPAGATION APPLICATIONS. Dong-Hoa Lam, The Ohio State University, Columbus, Ohio 43210

The feasibility of a direct time domain solution for one dimensional electromagnetic pulse propagation problems in isotropic media by finite difference methods is investigated. Optimum difference schemes are identified for the time-dependent wave equation, where stability is guaranteed, and solutions are obtainable to any degree of desired accuracy. We have also developed effective techniques for simulating the infinite boundary as well as for efficient moving time window calculations. Since the techniques can be easily applied to a multitude of homogeneous layer, EMP propagation problems in inhomogeneous and time-varying media can be readily solved provided that the medium is approximated in a step-wise fashion.

The techniques are successfully applied to several problems. The following problems are considered; the time history of the propagation of a step source in a homogeneous lossy medium; the transmission of a gaussian pulse through the air/earth interface; the reflection of a sine-square pulse from a three layer lossy media; the reflected waveform of a step source from a Debye type dispersive interface. Various numerical insights which lead to the successful applications of the methods are discussed. Numerical evidence is given to demonstrate the superiority of the finite difference approach.

VI. 10-5 GEOMETRICAL OPTICAL APPROACH FOR ELECTROMAGNETIC WAVE PROPAGATION IN RECTANGULAR MINE TUNNELS. Samir F. Mahmoud and James R. Wait, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado 80302

Recent measurements [1] in mine tunnels have demonstrated the feasibility of UHF radio communication in mine tunnels. Waveguide type propagation is possible because the rectangular cross section of the tunnel has dimensions somewhat greater than a wavelength.

To analyze such a waveguide, we propose to use geometrical optical techniques to calculate the vector fields of a given source in the tunnel for ranges up to about 2000 m. We consider excitation by both horizontal and vertical antennas located in the tunnel. Also, the four walls of the tunnel are treated as generally lossy dielectric media.

For the special case where the two side walls are assumed to be perfectly reflecting with the other two walls imperfectly reflecting, it is possible to obtain the various modes of propagation in the tunnel [2]. For this case, a comparison of the results obtained using mode and ray theories is presented. We then indicate how the geometrical optical approach can be used to calculate the fields in the rectangular guide when all four walls are imperfectly conducting.

In this latter case, there is a fundamental difficulty [3] in developing a modal equation. In fact, it turns out that the "modes" are intrinsically coupled.

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1. See Proceedings of Thru-the-Earth Electromagnetics Workshop, sponsored by U. S. Bureau of Mines, Colorado School of Mines, Golden, August 1973. (Available from N.T.I.S., Springfield, VA).
2. e.g. see S. F. Mahmoud and J. R. Wait, Radio Science, 9, No. 3, March 1974.
3. J. R. Wait, Electronics Letters, Vol. 3, No. 2, 87-88, February 1967.

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VI. 10-6 PROPAGATION CHARACTERISTICS OF A HORIZONTAL CONDUCTING WIRE LOCATED ABOVE OR BURIED IN THE EARTH. David C. Chang and James R. Wait, Department of Electrical Engineering, University of Colorado, Boulder, Colorado 80302; and Robert G. Olsen, Department of Electrical Engineering, Washington State University, Pullman, Washington, 99163.

The propagation constant of em waves on a long, horizontal thin conducting-wire in the presence of a dissipative earth is determined from a modal equation that satisfies the boundary conditions on the wire, at the air-earth interface and at infinity. Analytical expressions are obtained for various situations: an elevated wire, a wire in the interface, a buried bare or insulated wire, under the assumption of a small height or depth (compared with the skin-depth) and no angular variation around the wire. These conditions are usually encountered in VLF and ELF applications except for the deeply buried thin wire where the effect of the interface is negligible any way. Significance of our result as applied to a horizontal ELF radiating structure such as the Sanguine antenna will be discussed.

For an elevated wire, the dominant propagating mode is a slow-wave mode which reduces to the TEM-mode of a two-wire transmission-line for sufficiently large ground conductivity. In addition to this mode, we have found yet another possible mode of propagation which generally exhibits a fast-wave nature. It is related analytically to the well-known poles in the Sommerfeld integral representation and critically dependent upon the existence of the thin-wire. However only when the height of the wire is comparable to the free-space wave length can this mode be excited more effectively by a voltage generator on the wire and has a smaller attenuation rate than that of the slow-wave mode. Hence, its usefulness lies mainly in the higher frequency application. Some numerical results on the characteristics of these two modes will be presented.

VI. 10-7 PERCENTAGE ERROR CAUSED BY USING LEONTOVICH IMPEDANCE BOUNDARY CONDITION. Yu-Ping Liu, Intelcom Rad Tech, Box 80817, San Diego, CA 92138

The impedance boundary condition used for the description of the earth material is first applied by Leontovich. The general derivation is given by Senior. This condition is valid only under the assumption that the refractive index is greater than 1. There is no quantitative criterion set for the values of n. The boundary of n cannot be ascertained in general, since the exact criterion depends on the geometry and the material constant of the lossy material. In this paper, an attempt is made to find the difference between the approximate solution which used the impedance boundary condition and the exact solution which used the continuity condition between interfaces.

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The percentage error between the approximate and exact solutions for a particular geometry is calculated for different values of n. A general conclusion is reached on how good the impedance boundary condition is for this problem.

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NUMERICAL METHODS II

R. F. Harrington, Chairman

VI. 12-1 SCATTERING BY NONCIRCULAR CONDUCTING CYLINDERS WITH THIN DIELECTRIC COATING.* J. H. Richmond and N. N. Wang, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, Columbus, Ohio 43212

The reaction concept is employed to formulate an integral equation for scattering by a dielectric-coated conducting cylinder with noncircular cross section. The surface-current density on the conducting surface is expanded with sinusoidal bases for the TE polarization and rectangular-pulse bases for the TM polarization. The dielectric layer is modeled with the equivalent polarization currents radiating in free space.

Maxwell's equations and the boundary conditions are employed to express the polarization-current distribution in terms of the surface current density on the conducting surface. By enforcing reaction tests with an array of electric test sources, the moment method is employed to reduce the integral equation to a matrix equation. The matrix has the same size for an uncoated cylinder and a cylinder with a thin dielectric coating. Inversion of the matrix equation yields the current distribution, and the scattered field is then obtained by integrating the current distribution.

Scattering data are presented for circular and square cylinders with a thin dielectric coating for TE and TM polarizations. The data for the coated circular cylinders are compared with the rigorous eigenvalue solution. It is found that the polarization-current model is more satisfactory than the popular surface-impedance model.

A principle of similitude is presented for uncoated cylinders, and universal curves are given for the echo width as a function of frequency and angle of incidence.

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*This work was supported in part by Grant NGL 36-008-138 between National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, and The Ohio State University Research Foundation, Columbus, Ohio.

VI. 12-2 SCATTERING FROM A SEMI-INFINITE HOLLOW CYLINDER WITH AN INTERIOR TERMINATION. C. A. Chuang and C. S. Lang, Convair Aerospace Division, General Dynamics, Fort Worth, Texas

This investigation concerns with the scattering characteristics of electromagnetic waves from the interior of a semi-infinite hollow circular cylinder with an arbitrary termination located a finite distance from the open end. Impinging upon this structure, a plane wave is scattered at the open end and generates waveguide modes propagating towards the interior of the cylinder. The multiple-scattering of these modes between the interior termination and the open end can be described conveniently by the generalized scattering matrix approach. The various scattering matrices have been derived by an application of the Wiener-Hopf technique at the open end and through use of waveguide theory at the termination. The formal expressions for the back-scattered field from the cylinder have been formulated [1], but are too complex to be useful. Therefore, an asymptotic solution, which is valid at high frequency and for moderately large incident angles from the axis of the cylinder, has been derived [2]. The radar cross-section returns from a circular cylinder with a perfectly conducting flat-surface termination has been calculated. Comparison of the computed results and some available theoretical and measured data shows good agreement. Some applications and extensions of the theory will be discussed.

1. C. A. Chuang, "High-Frequency Backscattering from an Airborne Target," Ph.D. Dissertation, University of Illinois, Urbana, Illinois, 1973.
2. C. Liang, C. A. Chuang and S. W. Lee, "High Frequency Scattering from an Open-Ended Semi-Infinite Cylinder," 1973 USNC/URSI Meeting Digest, Colorado, August 21-24, 1973.

VI. 12-3 A SYSTEMATIC APPROACH TO THE SMALL HOLE COUPLING PROBLEM. R. Mittra and Y. Rahmit-Samii, Electromagnetics Laboratory, Department of Electrical Engineering, University of Illinois, Urbana, Illinois 61801

During the last two decades a great deal has been written in the literature on the problem of electromagnetic coupling through a small aperture in a screen, two of the foremost contributors being Bethe [1] and Bouwkamp [2]. Both have derived the leading terms of the Rayleigh series expansion of the aperture field in ascending powers of the wave number k, although they have followed totally different procedures to arrive at the solution. Bouwkamp has constructed the solution of three, coupled, integro-differential equations for the two components of the aperture field and has shown that the O(k) term in Bethe's solution, derived via the use of scalar and vector potentials, is not complete. Neither of these two approaches seem capable of convenient generalization to a non-separable aperture shape e.g., a rectangle.

In this paper we present a new and systematic formulation of the low frequency aperture coupling problem which is not limited to separable geometrics. Starting with the new form of integral equations recently derived for the complementary thin-plate problem [3, 4], we expand both sides in powers of k to derive a set of integral equations to be solved for the aperture field. For the first two terms the kernels of the resulting integral equations are identical and are identifiable as simply the scalar Green's function for the corresponding electrostatic problem. We show that these integral equations associated with the expansions in powers of k can be exactly inverted for the case of circular aperture using the dual integral equation technique [5]. The solution, thus obtained, not only agrees with Bouwkamp for both O(o) and O(k) terms, but identifies the error in Bethe's solution as well. For other shapes, such as rectangles, a numerical solution of simple, electrostatic integral equations allows one to construct a unique solution to the problem upon applying the boundary condition that the electric field is zero at the rim.

In summary, the principal advantage of the approach is its ability of constructing the solution for non-separable geometries in a systematic manner, a feature which is not present in either Bethe's or Bouwkamp's methods.

Acknowledgement. The work reported in this paper was supported by the Harry Diamond Laboratories and Defense Nuclear Agency under Contract DAAG-39-73-C-0231.

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2. C. J. Bouwkamp, "Diffraction Theory," Phillips Res. Rep., No. 5, pp. 401-442, December 1950.
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5. R. Mittra, "Solution of a Class of Dual Integral Equations," Technical Report No. 51, Electromagnetics Laboratory, University of Illinois, 1961.

VI. 12-4 BROADSIDE RADAR CROSS SECTION OF THREE-DIMENSIONAL CONDUCTING RECTANGULAR TARGETS. Leonard L. Tsai, University of Mississippi, University, Mississippi 38677

Radar cross section analysis for three-dimensional conducting rectangular objects is performed via integral equation techniques. The solution for the current with plane wave incidence is obtained by applying moment method to the magnetic field integral equation; from which RCS readily follow. The major difficulty of numerical solution for three-dimensional scattering problems, i.e., the prohibitively large matrix sizes necessary to adequately sample current variations, is circumvented using symmetry arguments. Specifically, it is shown that for the conducting rectangular box, matrix sizes may be reduced eightfolds, even for arbitrary incidence. The theory for broadside incidence has been presented earlier [1]. The emphasis in this paper will be on presentation of RCS trends and the procedures to analyze arbitrary incidence.

Calculated broadside radar cross sections for both the thick square plate and the cube show excellent agreements with measured results in the literature (for side lengths up to 1λ). To gain perspective on how RCS vary for different rectangular shapes, several cases are calculated as functions of frequency. Thick plates with sides ratios of 2 to 1 and 4 to 1 are studied for two polarizations. The results show quantitatively plate size lower limits where either physical optics or equal area criterion cease to be applicable. For square boxes with varied depths, resonances in RCS are directly correlated with the depth changes. Finally, a thick plate with 2 to 1 side ratios, examined with edge on incidence, yield results which can be useful in airfoil radar signature studies.

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VI. 12-5 NEAR FIELD COUPLING BETWEEN TWO CORNER REFLECTORS.
M. F. Iskander and M. A. K. Hamid, Department of Electrical Engineering, University of Manitoba, Winnipeg, Canada R3T 2N2

A solution for the near field coupling between two corner reflectors or two wedges of finite length is obtained using the iterative technique of overlapping regions. The excitation is assumed to be due to an E-polarized line source, and it is shown that by using the Green's functions for the four sub-regions interior and exterior to both reflectors, the problem is reduced to the solution of a system of integral equations of the Fredholm type.

The iterative procedure is initiated by assuming the fields on the non-metallic boundaries of the sub-regions of the first reflector. Using an integral formulation based on the Green's function method and field continuity at a common boundary of the over-lapping region, we calculate the fields on the non-metallic boundaries of the sub-regions of the second reflector. The latter is consequently used to calculate a second order approximation for the initially assumed fields and so on. A reasonable approximation of the fields initially assumed is obtained by considering an induced line source at each of the edges of the first reflector. The amplitude of these fields is then related to the actual source intensity by equating the field expansions for the two reflectors at a common boundary of the overlapping region. Since this requires a single coordinate system, we express Graf's addition theorem for cylindrical functions in a more convenient form (involving a second infinite summation) for general validity at any observation point.

The results for the axial coupling are presented graphically as a function of the separation distance. The method is shown to be sufficiencly accurate and reliable for predicting suitable near field correction factors which permit ready calculation of the far field gain and radiation pattern of a corner reflector.

VI. 12-6 AN INTEGRAL EQUATION FOR THE IMPULSE RESPONSE OF A COLD STRATIFIED PLASMA. K. G. Gray,* Analytic Services Inc., Falls Church, Virginia 22041

In this paper the multiple-scattering technique is utilized in formulating an integral equation describing the response of a cold stratified plasma to a plane impulsive electromagnetic wave at vertical incidence. The effects of electron collisions with neutral particles and a vertical magnetic field are included in the analysis.

The integral equation is derived by considering the plasma to be comprised of an infinite number of infinitesimally thin electron sheets. The total scattered field is found by summing over the elementary waves scattered from the thin sheets that have had time to reradiate to the height of observation. These elementary waves all travel at the free-space velocity to this height where they combine to form the total scattered field. As an example of this method the integral equation is solved numerically for a linear plasma half space.

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*This work was performed in partial fulfillment of the Ph.D. requirements while the author was at the Aeronomy Laboratory, University of Illinois.

VI. 12-7 THE IMPULSE RESPONSE OF A COLD STRATIFIED PLASMA BY A MONTE CARLO METHOD. K. G. Gray,* Analytic Services Inc., Falls Church, Virginia 22041 and S. A. Bowhill, Aeronomy Laboratory, Department of Electrical Engineering, University of Illinois, Urbana, Illinois 61801

In this paper a Monte Carlo method is presented for finding the response of a cold stratified plasma to a plane impulsive electromagnetic wave at vertical incidence. The effects of electron collisions with neutral particles and a vertical magnetic field are included in the analysis.

The Monte Carlo method is developed utilizing a multiple-scattering technique that takes into account the effects of individual free electrons on the total response. In previous work the multiple-scattering technique is viewed as a continuous scattering process, where by continuous we mean the electrons are uniformly distributed through any horizontal plane in the plasma. In this paper a different viewpoint on the physical process is adopted. The continuous scattering process is replaced with a sequence of scatters, individual orders of scatter are computed from an ensemble of scatters, and the total scattered field is the sum over all orders of scatter. A Monte Carlo simulation of the scattering process is performed, and the resulting relative frequencies are used to approximate the orders of the scatter. Results of the Monte Carlo method are presented for the uniform plasma half space.

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*This work was performed in partial fulfillment of the Ph.D. requirements while this author was at the Aeronomy Laboratory, University of Illinois.

VI. 12-8 ANALYTICAL STUDIES OF ELECTROMAGNETIC PROBLEMS WITH MACSYMA. J. A. Kong, Department of Electrical Engineering and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

MACSYMA is a computer language which is useful in obtaining solutions in analytical forms. It has capabilities of manipulating algebraic expressions involving numbers, variables, and functions. With which one can differentiate, integrate, take limits, solve equations, factor polynomials, expand functions in power series, plot curves, create new functions and extending existing functions and operations. The basic mode of operation is conversational. It is implemented on a time-sharing computer system (DEC-PDP 10).

Numerical solutions of electromagnetic problems by using conventional computer languages have been progressing very rapidly in the past few years. Various techniques in numerical analysis have been applied. The major disadvantage in numerical solutions is the lack of physical interpretation. With MACSYMA, one can obtain analytical solutions as well as numerical solutions. A semi-numerical analysis can be conveniently carried out where spurious constants are assigned numerical values while the important physical parameters are kept as variables throughout the calculations. In the following we illustrate the analytical capabilities of MACSYMA by three examples. It is conceivable that this powerful tool will considerably influence future approaches to the solutions of electromagnetic problems.

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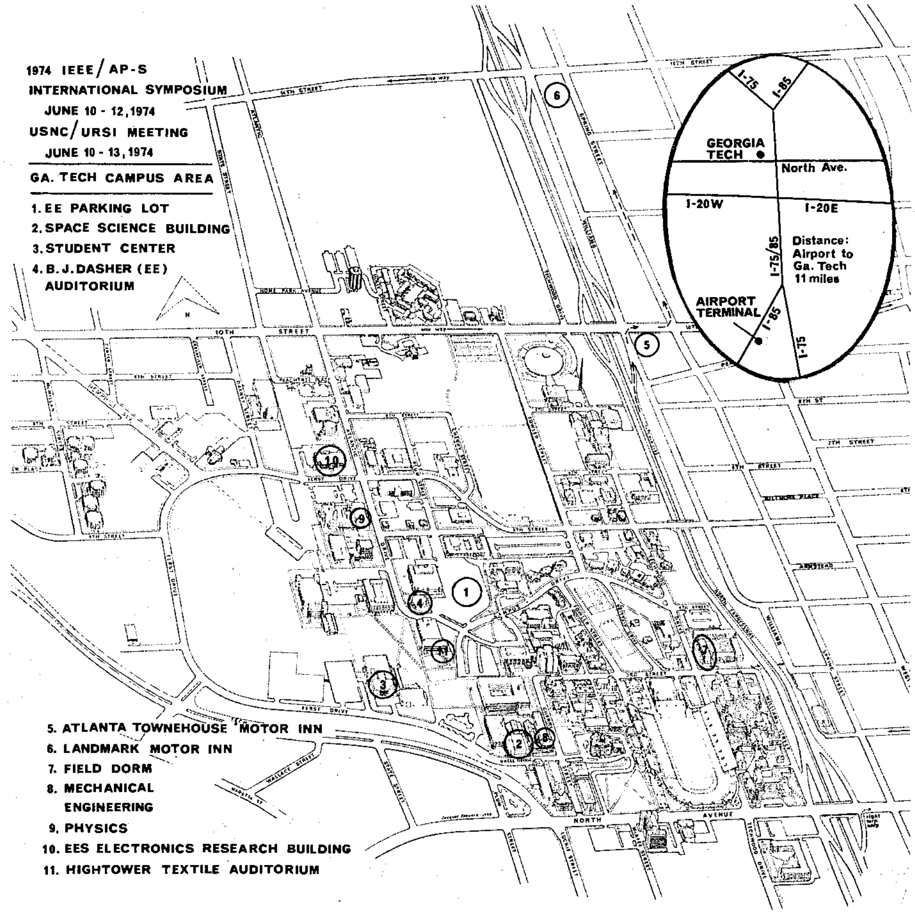
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