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

1970 FALL MEETING
15 - 17 September

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

THE OHIO STATE UNIVERSITY

Columbus, Ohio

SCHEDULE OF SESSIONS

Time	9:00 - 12:15	2:00 - 5:15	6:15 - 7:30
Tuesday	Joint Session with G-AP— 131 HH*, page 2	II. 1-113 EL, page 10 III. 1-111 EL, page 40 VI. 1-035 HH, page 56	Reception — Ballroom Foyer, NH Banquet — Presidential Ballroom, NH @ 7:30
Wednesday	II. 2-113 EL, page 16 III. 2-111 EL, page 44 VI. 2-035 HH, page 63 VI. 3-035 HH, page 66	I. 1-765 EL, page 5 II. 3-113 EL, page 22 III. 3-111 EL, page 48 VI. 4-035 HH, page 69	
Thursday	II. 4-113 EL, page 27 III. 4-111 EL, page 51 VI. 5-031 HH, page 76 VI. 6-035 HH, page 80	II. 5-113 EL, page 33 VI. 7-035 HH, page 87	

*LOCATION OF SESSIONS

HH — Hitchcock Hall, 2070 Neil Ave.

EL — Electronics Laboratory, 2015 Neil Avenue

NH — Neil House, 41 South High Street

BUSINESS MEETINGS —

U. S. National Committee Meeting, Monday, 8:00 P.M., Parlor 11, NH.

Comm. I: Thursday, 9:00 A.M., 765 EL

Comm. II: Wednesday, P.M., following II. 3, 113 EL

Comm. III: Wednesday, P.M., following III. 3, 113 EL

Comm. VI: Wednesday, P.M., following VI. 4, 035 HH

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attendance (paid) 435

INTERNATIONAL SCIENTIFIC RADIO UNION
U.S.A. NATIONAL COMMITTEE

The National Committee maintains the following technical commissions. Current chairman and their affiliations are given.

1. Radio Measurement Methods and Standards
   Dr. Helmut M. Altschuler
   Institute for Basic Standards, 272.10
   National Bureau of Standards
   Boulder, Colorado 80302

2. Radio and Non-ionized Media
   Dr. Charles I. Beard
   Boeing Scientific Research Labs.
   P. O. Box 3981
   Seattle, Washington 98124

3. On the Ionosphere
   Dr. Erwin Schmerling
   Code S.G.
   NASA
   Washington, D. C. 20546

4. On the Magnetosphere
Dr. Jules Fejer
Dept. of Applied Electrophysics
University of California
La Jolla, California 92037

5. Radio and Radar Astronomy
Prof. Marshall H. Cohen
Owens Valley Radio Obsv.
California Institute of Technology
Pasadena, California 91109

6. Radio Waves and Transmission Information
Dr. Leopold B. Felsen
Polytechnic Institute of Brooklyn
Graduate Center, Route 110
Farmingdale, New York 11735

7. Radio Electronics
Prof. Robert Collins
Department of Electrical Engineering
University of Minnesota
Minneapolis, Minnesota 55455

OTHER MEMBERS OF THE U.S.A. NATIONAL COMMITTEE

Members-at-Large

Dr. W. I. Axford	Dr. David C. Hogg
Mr. H. V. Cottony	Mr. I. Katz
Prof. G. A. Deschamps	Mr. W. W. Mumford
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Institute of Electrical and Electronics Engineers:

Prof. E. Weber

United States Government

Commerce	Mr. A. H. Shapley
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Army	Mr. F. H. Dickson
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NSF	Dr. E. H. Hurlburt
ODTM	Mr. W. Dean, Jr.

Honorary:

Dr. H. H. Beverage
Prof. A. H. Waynick

Ex-Officio:

Officers of URSI resident in the United States (including honorary presidents, chairman and vice-chairman of commissions)

Immediate Past President	Prof. S. Silver
Vice-President	Prof. H. G. Booker
Chairman of Commission II	Prof. W. E. Gordon
Chairman of Commission VII	Prof. M. Chodorow
Vice-Chairman of Commission III	Prof. S. A. Bowhill
Vice-Chairman of Commission IV	Dr. F. L. Scarf
Vice-Chairman of Commission VI	Prof. K. M. Siegel
Foreign Secretary of National Academy of Sciences	Prof. H. S. Brown
Chairman of Division of Physical Sciences, NAS	Prof. R. Smoluchowski

DESCRIPTION OF
INTERNATIONAL UNION OF RADIO SCIENCE

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 it 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.

The officers of the International Union are:

President:	Prof. W. Dieminger (West Germany)
Immediate Past-President:	Prof. S. Silver (USA)
Vice-Presidents:	Prof. W. J. G. Beynon (UK) Dr. J. Groszkowski (Poland) Prof. H. G. Booker (USA) Prof. M. J. Voge (France)
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Honorary Presidents:	Mr. B. Decaux (France) Dr. R. L. Smith-Rose (UK) Mr. J. A. Ratcliffe (UK) Prof. C. Manneback (Belgium)

The Secretary's office and the headquarters of the organization are located at 7, Place Emile Danco, Uccle, Brussels 18, Belgium. The Union is supported by contributions (dues) from 37 member countries. Additional funds for symposia and other scientific activities of the Union are provided by ICSU from contributions received for this purpose from UNESCO.

The International Union has seven permanent bodies called "Commissions" for centralizing studies in the principal technical fields. In addition, Commission VIII has been newly established on a provisional basis. The names of the Commissions and the chairmen are as follows:

I. Radio Standards and Measurements
Prof. M. E. Zhabotinskii (USSR)

II. Radio and Non-ionized Media
Prof. W. E. Gordon (USA)

III. On the Ionosphere
Prof. K. Rawer (Germany)

IV. On the Magnetosphere
Dr. J. W. Dungey (UK)

V. Radio Astronomy
Dr. C. A. Muller (Netherlands)

VI. Radio Waves and Circuits
Prof. H. M. Barlow (UK)

VII. Radio Electronics
Prof. M. Chodorow (USA)

VIII. On Radio Noise of Terrestrial Origin
Prof. R. Rivault (France)

Every three years the International Union holds a meeting called the General Assembly. The latest of these, the XVI'th, was held in Ottawa, Canada, in August 1969. 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. The new activity in the exploration of space and the extension of our 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.

JOINT G-AP/URSI SESSION

Professor Henry G. Booker, Chairman

0900 Tuesday, September 15 131 Hitchcock Hall

1. WELCOME TO COLUMBUS AND THE OHIO STATE UNIVERSITY by Dr. Gordon B. Carson, Vice President, The Ohio State University, Columbus, Ohio.

2. VERY-LONG-BASELINE INTERFEROMETRY EXPERIMENTS. Marshall H. Cohen, California Institute of Technology, Pasadena, California.

3. ATMOSPHERIC LIMITATIONS ON SATELLITE COMMUNICATIONS AT FREQUENCIES EXCEEDING 15 GHz. D. C. Hogg, Bell Telephone Laboratories, Holmdel, New Jersey.

4. SOME RADIO AND OPTICAL OBSERVATIONS OF IONOSPHERIC MODIFICATION BY A NEW HIGH POWER HF GROUND-BASED TRANSMISSION. W. F. Utlaut, ESSA Research Laboratories, Boulder, Colorado.

5. GENERAL PURPOSE COMPUTER PROGRAMS FOR FIELD PROBLEMS. Roger F. Harrington, Syracuse University, Syracuse, New York.

JOINT G-AP/URSI SESSION

Professor Henry G. Booker, Chairman

0900 Tuesday, September 15 131 Hitchcock Hall

1. WELCOME TO COLUMBUS AND THE OHIO STATE UNIVERSITY, Gordon B. Carson, Vice President, The Ohio State Univeristy, Columbus, Ohio.

2. VERY-LONG-BASELINE INTERFEROMETRY EXPERIMENTS. M. H. Cohen, California Institute of Technology, Pasadena, California

VLB observations have been made at many wavelengths from 2.8 to 270 cm. The highest resolution was obtained on the Greenbank-Crimea baseline, 2.9 x 10^8 wavelengths long at 2.8 cm, on which 2 quasars showed interference fringes. The observations between Goldstone, California, and Canberra, Australia (8.1 x 10^7 wavelengths at 13 cm) were the most sensitive, with a minimum detectable flux of 0.3 fu. These gave fringes on 56 sources, and there are sufficient data to calibrate the interferometer and derive accurate positions, based on time delay and fringe rate. Typical accuracy is two seconds of arc. At 270 cm, observations were made on the baselines Owens Valley-Greenbank-Arecibo. Three sources showed fringes. Preliminary values for the diameters are in rough agreement with values expected from the theory of stellar scintillations.

3. ATMOSPHERIC LIMITATIONS ON SATELLITE COMMUNICATIONS AT FREQUENCIES EXCEEDING 15 GHz. D. C. Hogg, Crawford Hill Laboratory, Bell Telephone Laboratories, Incorporated, Holmdel, New Jersey

Interest in use of frequencies exceeding 15 GHz for satellite communications is steadily increasing, and indeed it is planned to share frequency bands between satellite and terrestrial systems. It is advantageous to consider use of two polarizations, thereby increasing the information capacity by perhaps a factor of two. However, fundamental limitations are imposed on such systems by effects of rain: attenuation, scattering, and depolarization. The present status of measurement and theory of these effects in the 15 to 100 GHz range is discussed.

From terrestrial measurements, attenuation is known to depend on polarization; both this dependence and depolarization of the waves are caused by the oblateness of the raindrops. The role that path diversity can play in improving the reliability of satellite systems is evaluated from measured data. The techniques involved in measuring at the various frequencies are discussed as time permits. The use of radiometer measurements of noise from the rain for determining the attenuation is discussed in some detail. Since the measuring equipments are required to operate continuously in order to produce reliable statistics, advantage of solid-state technology is taken where possible.

4. SOME RADIO AND OPTICAL OBSERVATIONS OF IONOSPHERIC MODIFICATION BY VERY HIGH POWER HF GROUND-BASED TRANSMISSION. W. F. Utlaut, Institute for Telecommunication Sciences, ESSA Research Laboratories, Boulder, Colorado

Some early observations of significant ionospheric modification resulting from F region heating by an HF transmitting facility located near Boulder, Colorado, having an average power-aperture product of the order of 10^4 megawatt-meters^2 are reported here. The high power facility was designed and constructed by the Institute for Telecommunication Sciences, ESSA, Department of Commerce, to carry out a variety of propagation and telecommunication studies. The transmitter can produce 2 megawatts CW and may also be pulsed. For ionospheric heating, a 10-element ring array antenna, with about 20 dB gain, is used. This transmits a right- or left-handed circularly polarized, vertically directed, beam over the range of 5 to 10 MHz.

Salient effects observed in ionosonde records following turn on of the heating transmitter are: (a) a prompt ionospheric response appearing within 30 seconds as a deformation in both the o and x traces at the virtual height at which the x component of the frequency used for heating was reflected, (b) a development and growth of spread F, starting within tens of seconds, frequently followed by distinct structure in both o and x traces, (c) a time varying broadband echo which, at times develops after ten minutes or more of heating and which also changes in range with time, and (d) variation in the strength of signals returned from the ionosphere. Photometric measurements of 6300Å airglow from the heated region indicate about a 30% rise in temperature. Infrared radiation at 1.27μ is observed at a lower height down the magnetic field line.

5. GENERAL PURPOSE COMPUTER PROGRAMS FOR FIELD PROBLEMS. Roger F. Harrington, Department of Electrical Engineering, Syracuse University, Syracuse, New York

In recent years a number of computer programs have been developed to give numerical solutions to large classes of field problems. These programs are user-oriented, requiring a minimum of input data and a choice of output data. Some examples of the type of programs available are (a) Laplace's equation in two-dimensional regions of arbitrary shape and with arbitrary combinations of Neumann, Dirichlet, and Cauchy boundary conditions, (b) wire antennas and scatterers of arbitrary shape with arbitrary excitation and loading, and (c) radiation and scattering from conducting bodies of revolution with arbitrary excitation and loading. The basis for such solutions is found in the theory of functional analysis and Hilbert space. A general exposition of the method is given in the author's monograph. "Field Computation by Moment Methods" (Macmillan, 1968).

A short history of the development of these methods for electromagnetic problems is given. Programs available, programs under development, and programs which might be written are described. Use of the programs for problems of engineering interest is demonstrated. A simple example is used to illustrate some of the details of solution. Restrictions due to limitations of computation time and storage are discussed. Unresolved problems and areas requiring further research are also discussed.

COMMISSION I

RADIO MEASUREMENT METHODS AND STANDARDS

Dr. Helmut M. Altschuler, Chairman

BUSINESS MEETING
9:00 A.M. Thursday, September 17 — 765 Electronics Lab.

COMMISSION I

1400 Wednesday, September 16 765 Electronics Lab.

ANTENNA AND RADIO MEASUREMENTS

George E. Schafer, Chairman

I. 1-1 A METHOD FOR MEASURING THE EFFECTIVE GAIN OF RADAR ANTENNAS. Paul L. Smith, Jr., South Dakota School of Mines and Technology, Rapid City, South Dakota

The effective gain of a radar antenna can be measured by using a standard-gain horn and a microwave power meter. No signal generator is required; the test signal is provided by the radar transmitter. The horn is used as a receiving antenna, and the received power is measured with the power meter. The effective gain of the radar antenna is then calculated from the Friis transmission formula.

The advantages of this method are:

(1) The gain measurement is made with the radar system in its actual operating configuration.

(2) The measurement incorporates all the losses (including ohmic and mismatch losses), and thus gives the effective gain of the antenna.

(3) When the entire radar system (including the receiver) is to be calibrated, measuring the antenna gain in this way causes any directional coupler error to cancel out in the radar equation.

The third advantage is important if the radar system is to be used for measuring radar cross-sections, or the reflectivities of distributed targets. One important application of this method is in the calibration of weather radars.

I. 1-2 A TABLE-TOP ANTENNA RANGE FOR S BAND. C. W. Bostian, Electrical Engineering Department, Virginia Polytechnic Institute, Blacksburg, Virginia. F. J. Tischer, Electrical Engineering Department, North Carolina State University, Raleigh, North Carolina.

An antenna range is described which is used to measure horizontal-plane radiation patterns of vertically polarized antennas operating above a conducting ground plane. Test antennas are mounted at the center of a 38.6 centimeters diameter turntable; a choke joint maintains a 3000 MHz short circuit between the moving turntable and the fixed portion of the ground plane. A quantitative evaluation of the choke joint's effectiveness is presented. The receiving antenna is a dielectric rod selected for its small physical aperture, high gain, ease of construction, and reduced backscatter. A circular wall of microwave absorber located 45 centimeters (4.5 wavelengths at 3000 MHz) from the turntable center attenuates reflections from the outer edge of the ground plane.

I. 1-3 ABSOLUTE CALIBRATION OF ANTENNAS AT EXTREMELY LOW FREQUENCIES (ELF). M. D. Clayton, University of Rhode Island, Kingston, Rhode Island.

In the study and detection of Schumann resonances in the earth-ionosphere cavity it is most desirable to know the absolute value of the electric and magnetic field strengths being detected. A low frequency magnetic field can be set up using a long solenoid or a current loop, whose field characteristics are well known. This is not true, however, for the low-frequency electric field, the situation being complicated by the fact that most antennas used in measuring low-frequency natural phenomena have an electrical length approaching zero. This paper describes a method for obtaining an absolute field calibration for any monopole antenna whose electrical length is very short.

I. 1-4 CONSIDERATIONS IN EMP TESTING OF PHASED ARRAY ELEMENTS. Leonard C. Humphrey, General Electric Company, Electronics Park, Syracuse, New York. Richard Patterson, General Electric Company, Heavy Military Electronics Systems, Syracuse, New York.

Consideration is given to the problem of determining the waveform of the element response to a prescribed electromagnetic pluse waveform. The analytic approach is complicated by the fact that a large portion of EMP energy spectrum lies below the design frequency of the antenna element. An experimental approach appears to be most feasible, and the particular design considerations are presented in this paper.

The approach used in that of creating a plane EM wave in a parallel plate transmission line. Topics considered are the effects of plate proximity, the radiation of high frequency energy from the line, the development of directional field sensors, and the effect of forshortning of the ground plane. The results of measurements made with a typical test line will be presented.

I. 1-5 AN IMPROVED METHOD OF DISSEMINATING MICROWAVE POWER CALIBRATIONS, Glenn F. Engen, National Bureau of Standards, Boulder, Colorado.

The dissemination of microwave power measurement traceability is usually by a hierarchy of calibration laboratories. In the associated measurement procedures, which are well documented, the subject of mismatch (or corrections) plays a major role. In particular, the evaluation of mismatch corrections requires the measurement of complex reflection coefficients; and the accuracy of this measurement is limited, in part, by connector imperfections.

The application of recently developed "power equation" methods to this problem provides both a simplified determination of the mismatch correction and improved accuracy. In particular, the intermediate step of measuring the reflection coefficients is eliminated, and the precision connector requirement is greatly relaxed.

I. 1-6 PHASE DIFFERENCE MEASUREMENT OF SIGNAL DELAY IN A SATELLITE SYSTEM WITH APPLICATION TO NAVIGATION. Robert M. Copsey, Computer Sciences Corporation, Systems Engineering Division, Los Angeles, California.

The electron transit time phenomenon through any circuit produces an electrical phase difference between the input and output signals associated with that circuit. This phase difference is of particular importance whenever a circuit is to be used for precise signal delay measurements such as is done for ranging in navigation.

Navigation employing space satellites is an interesting application of the principle. To make a communication satellite useful for space navigation test or experiment, an accurate absolute phase difference measurement was made on the communication repeater subsystem prior to launch into orbit. Advanced RF phase measurement techniques and equipment made possible an overall repeater subsystem measurement in all significant operating modes.

The test measurement technique is described. The results are given and interpreted. Reference to a related phenomenon known as group delay or envelope delay is provided.

COMMISSION II

RADIO AND NON-IONIZED MEDIA

Dr. Charles I. Beard, Chairman

COMMISSION II

1400 Tuesday, September 15 113 Electronics Lab.

MILLIMETER-WAVE PROPAGATION EXPERIMENTS UTILIZING THE ATS-5 SATELLITE

A. W. Straiton, Chairman
A. A. Ksienski, Organizer

II. 1-1 PROPAGATION STATISTICS FOR 15 AND 32 GHz EARTH-SPACE TRANSMISSIONS FROM THE APPLICATIONS TECHNOLOGY SATELLITE (ATS-V). Louis J. Ippolito, NASA/Goddard Space Flight Center, Greenbelt, Maryland

The Applications Technology Satellite (ATS-V) Millimeter Wave Propagation Experiment is the first flight experiment in the NASA Goddard Millimeter Wave Measurements Program for the determination of long - and short - term attenuation statistics of operational millimeter wavelength earth-space links as a function of defined meteorological conditions. The ATS-V Experiment, launched August 12, 1969, is providing the first propagation data from an orbiting geo-synchronous spacecraft in the 15 GHz (downlink) and 32 GHz (uplink) frequency bands. Several stations in the continental U.S. and Canada have been operating with the downlink transmission from the satellite since late September 1969.

In the first part of the paper, the experiment objectives and hardware implementations are briefly described. Included in the descriptions are the solid-state transmitters, receiver and signal processor on-board the spacecraft, and the ground receiver, transmitter, and antenna tracking systems. A multilevel computer processing program for the generation of downlink propagation statistics from five participating stations is also described.

In the second portion of the paper, attenuation statistics on 15 and 32 GHz transmissions with the NASA Rosman, North Carolina Station are presented. Comparisons of attenuation statistics with radiometric, weather radar, and rainfall data recorded at the station are included. Evaluation of fade durations, fade depths, outage times, etc., over hourly, daily, weekly, and seasonal periods are presented, and several unusual weather effects are highlighted.

Preliminary results on the long term computer generated statistics from the five participating stations will be described, with emphasis on the periods of similar meteorological conditions.

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II. 1-2 ATTENUATION, EMISSION AND BACKSCATTER BY PRECIPITATION. J. I. Strickland, Communications Research Centre, Ottawa, Canada

The attenuation by precipitation of a 15.3 GHz signal has been measured directly for slant paths of 30° elevation using the ATS-5 satellite. From simultaneous measurement of sky noise temperature at 15.3 GHz and backscatter at 2.9 GHz, values of attenuation are calculated for comparison with the values measured directly.

The receiving system consists of a 30 foot diameter antenna employing a modified Cassegrain feed, a mixer - preamplifier, and a phase-lock receiver. A small general purpose computer is used to position both the 30 foot antenna and an S-band radar antenna, and to acquire, display and store data on digital magnetic tape for subsequent analysis.

A collocated S-band weather radar is used to measure at 2.9 GHz the backscatter from precipitation. Normally, the radar is operated in an azimuthal scan mode at elevation angles of 5°, 10° and 20° to investigate the spatial distribution of precipitation echoes. At times during which attenuation of the ATS-5 signal is expected, however, the radar beam is directed along the propagation path from the satellite. The output from the radar logarithmic receiver is sampled at accurately determined times to provide digital A-scans. The mean reflectivity at each range is calculated, and path attenuations at 15.3 GHz are derived using the relation

$$A = k \int Z^{\beta} dr$$

A total power radiometer, consisting of the receiving antenna, mixer preamplifier, and a separate receiver of 10 MHz bandwidth, is used to measure the sky noise temperature at 15 GHz along the propagation path. The ground rainfall rate is measured at the receiving site using two high resolution tipping bucket rain gauges.

The attenuations calculated from the backscatter of 2.9 GHz radiation and those calculated from the measurement of sky noise temperature at 15.3 GHz are compared with the directly measured attenuation of the 15.3 GHz signal from the satellite. Generally good agreement is obtained. It is concluded that, under most meteorological conditions, attenuation at 15.3 GHz may be predicted from S-band radar measurements. Data from the radar are also used to give estimates of the variation of attenuation with elevation angle.

II. 1-3 PROPAGATION DATA FROM CRAWFORD HILL. A. A. Penzias, Bell Telephone Laboratories, Incorporated, Crawford Hill Laboratory, Holmdel, New Jersey

A considerable amount of precipitation data has been obtained in the 16- and 30-GHz sun tracker and 16-GHz radiometer programs underway at the Crawford Hill Laboratory. From the data obtained from radiometer measurements, one may calculate the attenuation expected on an earth-space path. Such attenuation calculations are in good agreement with sun tracker measurements. The present experiment was designed to check further the validity of the radiometer results by a direct comparison of the data obtained from a 16-GHz radiometer with the attenuation measured by transmission from the 15.3-GHz transmitter aboard the Fifth Applications Technology Satellite.

Data were taken at our site for rainstorms occurring during the time the satellite was transmitting in the three-month period following the initial ATS-5 transmitter turn-on in October 1969 as well as in the late spring and early summer of 1970. The maximum attenuation for which reliable data was obtained was 12 dB.

Whenever attenuation due to rain in excess of $\sim$1 dB was noted on the radiometer record, a corresponding dip in the received satellite signal was also recorded. Within the accuracy of this latter record, typically ±0.2 dB, definite correspondence of the records was obtained, indicating clearly that the radiometer data is a reliable measure of attenuation over the range of storm intensities measured so far.

II. 1-4 MILLIMETER WAVE PROPAGATION MEASUREMENTS WITH ATS-5 AT COMSAT LABS. A. Buige, H. Craft, Jr., J. Levatich and E. Robertson, COMSAT Labs

The Communications Satellite Corporation (COMSAT) has been an active participant in the ATS-5 millimeter wave propagation measurement program as an independent experimenter. The millimeter wave signals transmitted by the ATS-5 satellite at a frequency of 15.3 GHz have been received and recorded at a receiving terminal located at COMSAT Labs, Clarksburg, Maryland. This receiving station, located 35 miles northwest of Washington, D.C., yields propagation data relative to the Mid-Atlantic Coast region. The system has been in operation since October 1969.

The receiving terminal consists of a 16-foot diameter antenna, a low noise front end providing an 8 dB system noise figure and a signal processing receiver. When receiving signals from the main satellite transmitter, presently derated 9 dB from nominal performance, a measurement range for attenuation of about 15 dB is achieved. The system is capable of a 24 dB measurement range when receiving signals from the full power backup transmitter.

An important part of the millimeter wave propagation effort is the investigation of the relationship between attenuation and meteorological phenomena. To this end the measurement system has been equipped with a meteorological station consisting of a series of rain gauges, a weather radar, barometer, hydrometer and thermometer. A digital signal processor is used in the analysis of weather radar return.

The data that have been collected in the measurement program are presented in terms of probability densities and cumulative distributions of attenuation and correlations of attenuation with meteorological parameters.

This paper is based upon work performed in COMSAT Labs under the sponsorship of the International Telecommunications Satellite Consortium (INTELSAT). Any views expressed in the paper are not necessarily those of INTELSAT.

II., 1-5 A MILLIMETER WAVE DIVERSITY PROPAGATION EXPERIMENT.
P. Bohley, D. B. Hodge, ElectroScience Laboratory, Department of Electrical Engineering, The Ohio State University, Columbus, Ohio

This paper describes a 15.3 GHz diversity propagation experiment utilizing a transmitter on board the ATS-5 synchronous satellite. The ground-based facility consists of two complete receiving terminals, one fixed and the other completely transportable. Both receiving antennas are instrumented with bore-sight radiometers which view volumes coincident with the propagation paths of interest. The following meteorological parameters are recorded in addition to the signal amplitudes and radiometer temperatures: local wind speed, wind direction, temperature, rain rate, and relative humidity.

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Diversity data collected from these two terminals will be presented. This data is useful in characterizing the nature of the propagation path for a satellite-to-ground millimeter wave communication link and, in particular, assessing the effect of thunderstorm cell size and structure on two separated receiving terminals. The most recent results of the data analysis relating the signal amplitudes and radiometer temperatures at single and separated terminals will also be presented.

II. 1-6 EFFECTS OF RAIN ON AN EARTH-SATELLITE PATH AT 15 GHz. B. M. Fannin, A. W. Straiton, D. N. Pate, Electrical Engineering Research Laboratory, The Univeristy of Texas at Austin, Austin, Texas

The antenna system at The University of Texas terminal, located just north of Austin, utilizes two 10-foot parabolic dishes mounted side by side and operated as a summed interferometer. In addition to rain gauges and temperature and wind indicators, supporting electromagnetic probes of the path include a 35 GHz radiometer, a Ku-band radar and a 15.2 km line-of-sight Ku-band propagation link.

Though data for rain along the path is rather limited, several interesting periods have been recorded.

As others have also observed, a radiometer stands out as the superior wholly-ground-based probe for obtaining an indication of the attenuation along a path transversing the entire troposphere. However, Weather Bureau data is commonly the only information available on which to base attempted extrapolation of statistics gained at one station to other locals. In addition to correlating attenuation with general rain type, more detailed studies of attenuation for specific rain patterns enhance ones ability to perform meaningful extrapolations. For this type of endeavor radar is a most valuable tool.

RECENT RESULTS

II. 1-7 ATS-5, 15.3 GHz PROPAGATION MEASUREMENTS AT BOULDER COLORADO. Richard J. Brockway, Westinghouse Electric Corp., Boulder Colorado

II. 1-8 PROPAGATION MEASUREMENTS IN CENTRAL FLORIDA. D.E. Sukhia, Martin Marietta, Orlando, Florida

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II. 1-9 ATTENUATION AT 15 GHz IN COLORADO THUNDERSTORMS.
Jack B. Snider, ESSA Research Laboratories,
Boulder, Colorado

II. 1-10 EXPERIMENTAL REPORT ON 16 GHz AND 35 GHz RADIOMETERS ASSOCIATED WITH THE ATS-V MILLIMETER WAVE EXPERIMENT.
Yuichi Otsu, Radio Research Laboratories, Koganei-shi,
Japan.

COMMISSION II

0900 Wednesday, September 16 — 113 Electronics Lab.

RAIN AND WIND EFFECTS

David C. Hogg, Chairman

II. 2-1 A COMPARISON BETWEEN MEASUREMENTS OF SKY BRIGHTNESS TEMPERATURE AND TRANSMISSION LOSS AT 15.3 GHz.

H. D. Craft, Jr., COMSAT Labs

For the measurement of small to moderate transmission losses caused by precipitation in the atmosphere, radiometric techniques are often more simple or more flexible than those utilizing external signal sources such as the sun, a satellite, or an aircraft. However, since the transmission loss is a result of both absorption and scattering, rather than absorption alone, the usual simple relation between sky brightness temperature, transmission loss, and absorber physical temperature must be modified to include the additional effect of scattering.

To empirically determine the relation between sky brightness temperature and atmospheric transmission loss, a series of measurements have been made at the Laboratories of the Communications Satellite Corporation (COMSAT), located about 35 miles northwest of Washington, D. C. Transmission loss at 15.3 GHz, caused by precipitation, was measured using a 16-foot parabolic reflector antenna, a low noise receiver, and the sun or the ATS-5 satellite as the signal source. Simultaneous radiometric measurements of the sky brightness temperature, at 15.3 GHz, were made utilizing the same antenna and part of the same receiver.

Measurements were begun late in the Spring of 1970, and have continued through the summer. The available data, then, provide an empirical relation between the transmission loss, caused by precipitation, and the sky brightness temperature, for summer weather near Washington, D. C. In addition, it is possible to compare the relations so determined as they apply to apparent transmission losses experienced by signals from point or extended sources.

This paper is based upon work performed in COMSAT Labs under the sponsorship of the International Telecommunications Satellite Consortium (INTELSAT). Any views expressed in the paper are not necessarily those of INTELSAT.

COMMISSION II

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II. 2-2 A COMPARISON BETWEEN MONOSTATIC AND BISTATIC SCATTERING FROM RAIN AND THIN TURBULENT LAYERS.*

R. K. Crane, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts

Simultaneous measurements were made of the backscatter cross section and the bistatic scattering cross section of rain and thin turbulent layers. The radar measurements were made at a frequency of 1.3 GHz using the Millstone Hill Radar. The bistatic scattering measurements were made using CW transmission at 7.7 GHz with a 146-km separation between transmitter and receiver. The receive station was the Westford Communication Terminal with a 60-foot antenna. The transmitter was van-mounted and used either a 6-foot antenna or a standard gain horn. Stable frequency sources were used to allow doppler shift measurements on the bistatic scattering link. The measurements were made by fixing the pointing angles of the transmit antenna and scanning both the receive antenna and the radar to investigate the dependence of the scattered signals both on scattering angle and on the location of the scatterers.

The measurements of the scattering cross section of the thin turbulent layers were made in the near forward direction, the measurements of rain at a large number of scattering angles. System sensitivities allowed the measurement of scattering from turbulent layers at a 10-km height with a thickness, C_n^2 product of $10^{-13} N^2 m^{1/3}$ and from rain with a 10 mm/hr rate. Comparisons between the radar and bistatic measurements were in good agreement with the appropriate scattering theories.

* This work was sponsored by the Department of the Air Force.

II. 2-3 PRECIPITATION SCATTER MEASUREMENTS AT 6, 12 AND 18 GHz.

A. Buige, J. Levatich, R. Rocci, COMSAT Labs

The Communications Satellite Corporation is conducting a measurement program to evaluate precipitation scatter signals resulting from common volume coupling between earth stations and terrestrial radio relay links. An initial system of two 6-GHz receivers has been operating in the vicinity of the earth station in Etam, West Virginia since March 1969. This system was used to gather statistics for different common volume heights. In the Spring of 1970 the experiment was modified by the addition of a third receiving site and is currently being utilized to investigate the angular dependence of the scattered signals as well as the effect of non-interesting beams. At the same time a similar experiment is being conducted at 12 and 18 GHz in the vicinity of COMSAT Laboratories in Clarksburg, Maryland, using 10-foot antennas to simulate the earth station beams. This setup is used to obtain statistics and to investigate the relationship between the coupling and the gain of the receiving antenna.

The data collected so far indicate that there is reasonable correlation between statistical distribution of the received signals and rainfall rates obtained near the receiving terminals. A few instances of high signal levels, however, cannot be explained using the commonly accepted radar reflectivity and rainfall rate relationships, indicating the possible presence of scatterers other than raindrops in the common volume. At 12 and 18 GHz the problem is further complicated due to the dependence of the received signals on the attenuation along the path through the rain, so an attempt is being made to isolate the attenuation effects from the precipitation scatter ones through the use of a weather radar.

This paper is based upon work performed in COMSAT Laboratories under corporate R&D Task 151-4057.

II. 2-4 DUAL FREQUENCY MEASUREMENTS OF ATTENUATION BY RAIN.
R. A. Semplak, Bell Telephone Laboratories, Inc.,
Crawford Hill Laboratory, Holmdel, New Jersey

Rain-induced attenuations measured on a common 2.6 Km transmission path at 18.5 and 30.9 GHz are discussed. Included in the discussion are data obtained from a brief, but intense storm of April 2, 1970, where a rain-induced attenuation of 13.8 dB/Km was observed at 18.5 GHz, corresponding to a path-average rainrate of about 120 mm/hr. During that time, the attenuation at 30.9 GHz exceeded the 50 dB dynamic measuring range of that system.

A comparison is made of the ratio of measured attenuations $\gamma_m\left(\frac{30.9}{18.5}\right)$ to the ratio calculated using a Laws and Parsons drop-size distribution, $\gamma_c\left(\frac{30.9}{18.5}\right)$, as a function of rain rate. In general there is agreement, however, the inhomogeneous distribution of rainfall along the path is readily apparent from the measurements. The relationship of the ratio to the mode of the drop-size distribution is discussed.

II. 2-5 CROSS POLARIZATION OF MICROWAVE TRANSMISSION DUE TO RAIN.

David T. Thomas, Bell Telephone Laboratories,
Whippany, New Jersey

Cross polarization distortion (XPD) due to rain may be a serious problem for 18.5 and 30 GHz microwave communications, and a slight problem at 11 GHz. However, at present no measured data is available from which XPD system performance can be predicted.

This paper presents estimates of XPD based on a canted raindrop model. Average values of raindrop canting angle, Θ, are predicted from differential attenuation measurements of Semplak [1], assuming that the scatter (spread) in his data is due to variations in Θ (after accounting for expected measurement error). Independent measurements of canting angle by Saunders [2] agree nicely with expected values of Θ given here. Saunders also observed that drops are canted in BOTH directions in any given rainstorm which reduces the XPD. This was taken into account here.

The values of Θ obtained above are used to predict values of XPD due to rain for various rain rates at frequencies of 4, 6, 11, 18.5 and 30 GHz. Table 1 presents a few typical values based on $\Theta = 15°$, the value predicted above.

TABLE 1. XPDH* DUE TO RAIN

	Rain Rate		
	50 mm/hr	100 mm/hr.	150 mm/hr.
18.5 GHz 4.8 Km path	-30.2 dB	-24.5 dB	-19.2 dB
30 GHz 2 Km path	-34.0 dB	-27.8 dB	-22.7 dB

* XPDH is cross polarization distortion in the Horizontally polarized signal which is always the worst case.

These values have taken into account all of the factors mentioned earlier. They indicate the XPD due to rain is marginally acceptable in view of a -20 dB limit imposed by crosstalk considerations. (System engineers would prefer -25 dB.)

[1] Semplak, R. A., "The Effect of Raindrop Shape on Attenuation at 30.9 GHz", unpublished work.

[2] Saunders, M. J., "Cross Polarization at 18 and 30 GHz Due to Rain", unpublished work.

II. 2-6 LINE OF SIGHT MEASUREMENTS AT 34.89 GHz USING TWO SPACED TRANSMITTERS AND AN 8-ELEMENT RECEIVING ARRAY.

Jeffrey C. Harp, R. W. Lee, Alan T. Waterman, Jr.,
Stanford Electronics Laboratory, Stanford University
Stanford, California

Propagation data have been taken with a 34.89 GHz system on a 28 Km line-of-sight path. The system consists of two, horizontally spaced transmitters which are time-shared by an 8-element horizontal receiving array. This configuration of transmitter and receiver elements allows us to study the effects of the atmosphere upon signals which have traveled along several different paths through essentially the same volume of air. Simultaneously with the K_a-Band experiment, an 11.63 GHz signal is transmitted and received along a single path.

The recorded measurements consist of the amplitude of the X-Band signal and the amplitude and relative phase at each K_a-Band array element. These data are analyzed by calculating power spectra of the various data channels and by calculating correlations, time-lagged covariances and complex co-spectra between pairs of channels.

The results of the correlation and co-spectra analysis of the two-frequency data show good agreement with theory. From the K_a-Band amplitude covariances we are able to estimate the location along the path of the region of most intense scattering and also estimate the mean value and first derivative of the cross-path wind velocity field.

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II. 2-7 A FEASIBILITY STUDY OF THE MEASUREMENT OF TRANSVERSE WINDS USING THE SCINTILLATION PATTERN OF A LASER BEAM.

R. S. Lawrence, S. F. Clifford, and G. R. Ochs, ESSA Research Laboratories, Boulder, Colorado

We have demonstrated that the average wind speed across a laser beam can be measured by a simple, real-time correlation analysis of the scintillation pattern of the beam, observed through a pair of small apertures a few mm apart. The weighting function of the average along the path is adjustable by varying the size and spacing of the detector apertures.

We are investigating a more elaborate system intended to measure the profile, along the laser beam, of the transverse wind. Our feasibility study includes computer simulations and field tests, and is designed to elucidate the sensitivity, resolution, and reliability of the proposed method. An explanation of the method and up-to-date results of the feasibility study will be reported.

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THEORY

James R. Wait, Chairman

II. 3-1 RADIO WAVE PROPAGATION OVER ARBITRARILY STRATIFIED EARTH. E. Bahar, Electrical Engineering Department, University of Nebraska, Lincoln, Nebraska

In this paper, we analyze the problem of radio propagation over a surface whose upper layer (overburden) is of arbitrarily varying thickness. In the analysis, the fields at any point along the axis of the structure are expressed locally in terms of a complete set consisting of the surface wave and the radiation terms. The solutions are obtained in terms of coupled first order differential equations for the wave amplitudes of the surface wave and the radiation terms.

The method for deriving these solutions is compared with other techniques used to solve problems related to propagation over non-uniform surface wave structures. The present analysis is not restricted by the surface impedance concept or by special forms for the variations in the overburden depth. In addition, for the problem considered here, the local wave parameters may vary considerably over the entire path of propagation, thus making the use of perturbation analysis inefficient. The present analysis also enables one to resolve differences between recent experimental results and available analytical solutions.

II. 3-2 AN ALTERNATIVE INTEGRAL EQUATION FOR PROPAGATION OF RADIO WAVES OVER IRREGULAR TERRAIN. R. H. Ott, Institute for Telecommunication Sciences, ESSA Research Laboratories, Boulder, Colorado

Recently [1] an integral equation for calculating the attenuation of radio waves propagating over irregular, inhomogeneous terrain was derived. The integral equation is applied to three terrain profiles; a flat earth, a spherical earth and a Gaussian-shaped ridge. The solutions are compared with solutions obtained using classical methods such as the residue series and diffraction theory.

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[1] R. H. Ott and L. A. Berry, "An Alternative Integral Equation for Propagation Over Irregular Terrain", Radio Science, May 1970.

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For the first example; i.e., a flat earth, the solution of the integral equation is simply the inhomogeneous term. For the second example, the numerical results [2] for the attenuation function show 4-5 significant figure accuracy over almost the entire range of distances when compared with results obtained using the classical residue series.

The third, is a Gaussian-shaped ridge and the corresponding numerical results are in close agreement with those obtained using Hufford's [3] integral equation and also those obtained analyzing the Gaussian-shaped ridge with simple diffraction theory. This third example provides a realistic picture of the attenuation of a radio wave when it encounters a terrain anomaly, such as a large conducting ridge. This example also yields physical insight into a focusing phenomenon of the field just before the crest of a hill that cannot be predicted on the basis of simple diffraction theory, but is in fact predicted by the numerical solution of the integral equation.

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[2] Carl Wagner, "On the Numerical Solution of Volterra Integral Equations, J. of Math. and Phys., Vol. 32, pp. 289-401, 1953.

[3] G. A. Hufford, "An Integral Equation Approach to the Problem of Wave Propagation Over An Irregular Terrain", Quart. Appl. Math, Vol. 9, No. 4, pp. 391-404. 1952.

II. 3-3 VLF MODE PROPAGATION ACROSS AN ELEVATED COAST-LINE.

James R. Wait, Kenneth P. Spies, ESSA Research Laboratories, Boulder, Colorado

Calculations were given previously for the conversion coefficients at a flat land/sea boundary for VLF mode propagation in the earth-ionosphere waveguide[1]. Essentially, the technique is based on a

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1. Wait, J. R., and K. P. Spies (Sept. 1968), VLF mode calculations for propagation across a land/sea boundary in the earth-ionosphere waveguide, ESSA Tech. Rpt. ERL 87-OD 2 (available from the Supt. of Documents,U.S. Gov't Printing Office, Washington, D.C. 20402). [In Fig. 2, σ_1 and K_1 should be interchanged with σ_2 and K_2]

Kirchhoff formulation in the sense that reflections at the coast-line are neglected in the first-order working formulas. Quite recently the same problem has been solved using a Wiener-Hopf factorization procedure which demonstrates the validity of the Kirchhoff approach for the important modes in the VLF range [2,3]. In the earlier report, it was concluded that mode conversion by changes in the earth's surface impedance will play a role in VLF propagation, particularly when the path includes coast-lines separating the sea from poorly conducting land. Here, we extend the earlier analysis[1] to allow for the existence of an elevation change at the coast-line. Also, we outline the theoretical basis of the working formulas and then describe the calculations for a number of representative cases.

As indicated in the calculations, the conversion coefficients become appreciable in magnitude when the conductivity contrast is largest (i.e., propagation from sea to the poorly conducting land, or in the reverse direction). In the case of the elevated coast-line, the magnitude of the conversion coefficients is not modified significantly. In fact, in most cases, there is a compensating effect and the magnitudes are actually reduced below the value for a flat-lying coast-line. More significant is the appreciable phase shift(for seaward propagation) of the conversion coefficients resulting from elevating the land surface relative to the sea. This could be an important factor in estimating phase errors in VLF navigation systems. Also, of course, it means that the modal interference pattern will be shifted as a result of the land elevation, particularly when the propagation is from land towards sea. This factor should be borne in mind when interpreting VLF experimental data.

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2. Chang, D. C. (1969), VLF wave propagation along a mixed path in the curved earth-ionosphere waveguide, Radio Sci. 4(4), 335-346.

3. Wait. J. R. (1970), Factorization method applied to electromagnetic wave propagation in a curved waveguide with nonuniform walls (to be published in Radio Sci. July issue).

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II. 3-4 ON THE MEAN FIELD IN A RANDOM UNIAXIAL ANISOTROPIC UNBOUNDED MEDIUM. David F. Dence, John E. Spence, Department of Electrical Engineering, University of Rhode Island, Kingston, Rhode Island

Propagation in an unbounded medium, characterized by random fluctuations superimposed on a deterministic background both of which are assumed to be uniaxial anisotropic, is discussed. The procedure for obtaining the mean field is presented and generally follows the usual development of Dyson's equation (the diagrammatical representation of the integrodifferential equation for the mean field) except for modifications needed to treat the anisotropy. An example is used to illustrate the procedure required to obtain an effective dielectric constant and the plane wave dispersion relationship.

II. 3-5 ON THE VALIDITY OF THE BORN APPROXIMATIONS IN RANDOM WAVE SCATTERING. J. C. Hassab, J. Jarem, Department of Electrical Engineering, Drexel University Philadelphia, Pennsylvania

The scattering of a plane wave incident upon an appropriate random medium has been widely treated in the first or second order Born approximations. Evidently, there are two points of important considerations: 1. For a given scattering problem, does the Born-Neuman series converge to a unique solution? 2. If this series converges, how large an error is incurred by truncating it after the first or second term? In this paper, a simple quantitative criterion is derived that insures convergence to a unique solution, and sets an upper bound on the truncation error. This bound is expressed in terms of relevant parameters which characterize the convergence condition, the radiation, the scattering volume, and the structure of the medium. This result is established using the method of successive approximation, and the inequalities appropriate to the condition of quadratic summability of the kernel in the basic mean square.

II. 3-6 OPTIMIZATION OF POINT-TO-POINT COMMUNICATION ON THE MOON*. H. S. Hayre, J. F. Lindsey, University of Houston

This paper describes an extensive study which has been conducted to determine optimizations for point-to-point communication on the moon. Antenna heights between 5 feet and 100 feet are considered with a maximum transmitter power of 10 watts (40 dBm).

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The received level was set at 2 microvolts in 50 ohms except at lower frequencies where a noise correction was employed. The following factors were considered in the optimization - Bremmer series loss[1], free space loss, ground proximity losses[2], noise effects[3], antenna gains and variations in dielectric constant from 2.8 to 5.6 along with variations in conductivity from 10^{-3} mhos per meter to 10^{-8} mhos per meter. Specific ranges of interest were 5, 35, and 70 kilometers. Generally, for larger antenna heights of approximately 75-100 feet, the optimum frequency was found to be in the 1-5 MHz range. For the lower heights, the optimum was found to be in the 5-10 MHz. Finally, an analytical optimum of 5.6 MHz was found for the case of the dielectric constant of 5, conductivity of 10^{-6} mhos per meter and antenna heights of 6 feet for 5 foot monopoles.

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[1] Bremmer, H. Terrestrial Radio Waves (New York: Academic Press, 1949)

[2] Vogler, L. E. and J. L. Noble. "Curves of Ground Proximity Loss for Dipole Antenna," NBS TN-175, 20 May 1963.

[3] Vogler, L. E. "A Study of Lunar Surface Communications," NBS Monograph 85, 14 September 1964.

*This work was sponsered by NASA-Manned Spacecraft Center under Contract NAS-9-9851.

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SURFACE SCATTERING

Petr Beckman, Chairman

II. 4-1 AVERAGE SURFACE IMPEDANCE FOR HF GROUND WAVE PROPAGATION OVER PERIODIC SEA WAVES. R. K. Rosich, J. R. Wait, ESSA Research Laboratories, Boulder, Colorado

Oblique reflection of plane waves from a finitely conducting periodic surface is formulated. A matrix inversion method is used to solve for the coefficients of the scattered waves. The convergence of the procedure is shown to be good provided the wave heights are comparable with or less than a wavelength. The analytical technique employed is compared with the pioneering work on this subject by S. O. Rice who treated wavy dielectric interfaces and the recent important extension by D. E. Barrick who used the localized Leontovich boundary condition. The relationship to the often used Kirchhoff method is also discussed where we indicate that the latter has serious shortcomings for grazing incidence.

An "average surface impedance" Z_{avg} is defined as the ratio of the tangential electric field averaged over one wave period to the tangential magnetic field averaged in the same way. Numerical results for Z_{avg} are presented for HF propagation in the case where the surface wavelength is both less than and greater than the radio wavelength. In the latter case, rather interesting resonance phenomena occur for certain angles of incidence. It is shown that this effect is related principally to the transition from a propagating to an evanescent condition of the first grating lobe.

The numerical matrix inversion method used above is applied to a flat surface which has a periodic modulation of its surface impedance. This is an excellent check since there exists an exact analytical solution in the form of a partial fraction expansion.

II. 4-2 PREDICTED AND MEASURED GROUND-WAVE SEA CLUTTER SPECTRUM AT 6 MHz. Donald E. Barrick, Battelle Memorial Institute, Columbus Laboratories, Columbus, Ohio, Jerald A. Grimes, Raytheon Company, Spencer Laboratory, Burlington, Massachusetts

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The analysis of the interaction of HF/VHF radio waves with a rough sea is best undertaken using the classical boundary perturbation technique of Rice. The theory shows that scatter originates from gravity waves which satisfy the Bragg relationship in spatial period and orientation. For bistatic radar geometries, such waves have length $L = \lambda/(2 \sin \phi/2)$, where λ is the radar wavelength and ϕ is the bistatic angle from the forward direction to the scattering patch. These waves move in a direction bisecting the incidence and scatter lines to the patch, and produce a doppler shift $\Delta f = \sqrt{(g \sin \phi/2)/\pi\lambda}$, where g is the acceleration of gravity.

When omnidirectional bistatic antennas are located on the surface and a signal with effective pulse length τ is employed, sea scatter originates from elliptical annuli having the transmitter and receiver points as foci. The received signal spectrum consists of two "pedestals" above and below the carrier, whose frequencies are determined from the preceding Bragg relationship. Their exact shape is shown to depend upon the strengths and directionality of the ocean waves present near the antennas.

Recent measurements clearly confirm the above mechanism of HF sea scatter. On individual days with differing (but known) ocean wave characteristics, the measured spectra agree with expectations. Also, the measurements made at 6 MHz show that the lower cutoff of the Phillips wind-wave spectrum is not as sharp as predicted. In other words, the presence of swell or partially developed seas produced some ocean waves of the lengths required for scatter, even when the simple oceanographic models showed that winds were not sufficient to arouse fully developed waves of these lengths. The preliminary measurements made here along with the simple interpretation of the interaction mechanism suggest that HF scatter techniques should prove invaluable in the study and monitoring of sea states and ocean-wave spectra.

II. 4-3 A NOTE ON SCATTERING BY COMPOSITE ROUGH SURFACES.

A. K. Fung, Center for Research, Inc., University of Kansas, Lawrence, Kansas

The most often discussed model for a composite rough surface is a two-scale model, one made up of large gentle undulations on top of which small irregularities are superimposed. These two different scales of roughness are normally assumed to be generated by two independent stationary random processes. There are essentially two approaches to this problem: (1) the total contribution is taken to be the sum of the contributions from the two independent processes with an additional average performed on the contribution from the small irregularities over the large undulations [Semyonov, 1966; Wright, 1968; Bass, et al., 1968], and (2) the total contribution is computed from the composite surface as a whole [Fung and Chan, 1969]. The major difference between the two approaches is that the first approach assumes the contribution by the small irregularities to be resulting from non-coherent sources. More specifically the phase change due to the large undulations is ignored in computing the contribution by the small irregularities. The second approach includes the phase consideration and consequently gives rise to an additional term. While this term is normally insignificant compared with the contribution by the large undulations in polarized scattering, it is significant and accounts for the peak that shows up near vertical in depolarized scattering.

II. 4-4 MEASUREMENTS OF THE FREQUENCY DEPENDENCE OF BACKSCATTER FROM ROUGH SURFACES. John W. Rouse, Jr., Department of Electrical Engineering, Texas A&M University, College Station, Texas

The frequency dependence of backscatter from a smoothly undulating, randomly rough surface was examined experimentally using acoustic waves in water. The acoustic backscatter from a well-defined statistically rough surface was measured over a broad, continuous range of frequencies. The experiment resulted in discovering a transition region similar to that predicted by Spetner and Katz (1960), although their particular models do not adequately describe the observed phenomena. Following the procedure used by Katz (1966), the measured scattering coefficient data were fit to the function $\sigma^0 = a\lambda^{\alpha}$. The coefficient α was approximately zero from wavelengths longer than λ_0, the apparent transition wavelength, and equalled approximately 3.0 for wavelengths shorter than λ_0. The transition effect is attributed to a decrease in the components of the surface spectra near the transition wavelength λ_0. The effect is described using the model developed by Wright (1968).

It is noted that the same effect occurs for radar scatter from relatively calm seas in the wavelength region where the surface spectra has a dip caused by the transition between gravity waves and capillary waves (Guinard, 1970). Radar data recorded by the Naval Research Laboratories for low sea state surfaces shows a frequency dependence coefficient α of approximately 3.0 in the X-band region (Wright, 1968) and a coefficient α equal to approximately zero for longer wavelengths. The results presented demonstrate the "size filtering" effect of the incident wavelength and establishes that the effect is related to the surface spectra.

II. 4-5 THE WIND DEPENDENCE OF THE RADAR CROSS SECTION OF THE SEA FOR FREQUENCIES BETWEEN UHF AND X-BAND.
G. R. Valenzuela, Naval Research Laboratory, Washington, D. C.

The wind dependence of the radar cross section of the sea is obtained for radar frequencies of 428 MHz, 1228 MHz, 4455 MHz, and 8910 MHz. The data used in the analysis was obtained with the Naval Research Laboratory Four-Frequency Radar System off the coast of New Jersey in 1964, off Puerto Rico in 1965 and in the North Atlantic in 1969. The sea conditions ranged from 0.15 meter to 8 meter waveheights and windspeeds from calm to 24m/sec.

The wind dependence, for both vertical and horizontal polarization, for light winds (<5 m/sec) is found to be exponential and for strong winds is a fractional power of the windspeed. For vertical polarization the exponential law for C and X band seems to be related to the windspeed at which water waves become unstable ($\gtrsim$ 5 m/sec). The wind dependence in the plateau or saturation region (i.e., $\geq$ 5 m/sec) is found to be frequency dependent:

$U^{-0.148}$ for UHF

$U^{+0.175}$ for L band, and

$U^{+0.544}$ for C and X band.

The dependencies for C and X band in the saturation region are in agreement with the power law for the equilibrium range of the ocean spectra inferred from the radar cross section data for vertical polarization, $K^{-3.728}$, via composite scattering models.

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II. 4-6 LUNAR SURFACE DIELECTRIC CONSTANT DETERMINATION USING THE APOLLO LUNAR MODULE-TO-ASTRONAUT COMMUNICATIONS LINK*. Jefferson F. Lindsey, University of Houston, Houston, Texas

This paper describes an experiment which has been proposed for measuring the dielectric constant of the moon using present Apollo v.h.f. communications equipment and a portable field strength meter. The experiment uses the Brewster angle effect on the reflected wave for extraction of the dielectric constant. For the lunar module (LM) antenna height of 24 feet and the astronaut's field strength meter antenna height of 7 feet, it is found that the range of interest for observation of maxima and minima is between 31 and 130 feet. The maxima and minima occur as a result of the vector addition of the direct and reflected waves. The distance which corresponds to the Brewster angle can be used to predict the dielectric constant and the Brewster distance may be determined by measuring field strength over distance of interest. At distances closer than the Brewster (angle) distance, the phase shift from the Fresnel coefficient is very small; however, at distances greater than the Brewster (angle) distance, the phase shift from the Fresnel coefficient is close to -180 degrees. Thus, the location of the distance corresponding to the Brewster angle determines the composite dielectric constant over an area roughly the size of the first Fresnel zone.

II. 4-7 PANAMA CANAL ZONE JUNGLE MEASUREMENTS AT 50 AND 160 MHz. C. William Bergman, Jet Propulsion Laboratory California Institute of Technology, Pasadena, Calif.

In order to determine the extent to which path loss predictions based on computer models can be relied upon for communication planning in jungle terrain tests at 50 and 160 MHz were conducted in the Panama Canal Zone in October 1969. A transmitting site was selected on a hill surrounded by jungle. For that site and surrounding areas, ABC and contour plots were generated from the computer model. Path loss measurements were made at 68 sites at ranges 9 to 42 km for 50 MHz, vertical polarization. Measurements were made at 23 of the 68 sites for 160 MHz, vertical polarization. The receiving antenna was five feet above the ground. The

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*This work has been sponsered by the Manned Spacecraft Center under contract NAS 9-9851.

computed area prediction and measured results were compared. In the absence of good agreement, in order to diagnose the results, point-to-point predictions were made and comparisons made again. Sample measurements were made also for 50 MHz, horizontal polarization, and for 50 MHz, vertical polarization, with the transmitting antenna elevated an additional 1,200 feet. The data was analyzed by itself and in comparison with the computed data. The results are discussed. Consideration is given to the effect of the ground as an integral part of the measured and calculated path loss and to the effects of changing index of refraction.

A new technique for measuring field strength utilizing a low-power, tone squelch transceiver is described briefly. Path loss to 172 db could be measured.

Based on the results of this work, the author concludes that existing models and/or the concepts in which they are used need to be improved.

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TRANS-HORIZON PROPAGATION

Ralph Bolgiano, Jr., Chairman

II. 5-1 RESOLVING TURBULENT LAYER REFLECTIONS BY FORWARD SCATTER TECHNIQUES. Richard J. Doviak, Julius Goldhirsh, Albert Miller, The Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pennsylvania

Backscatter radars have been successful in detecting and characterizing clear air turbulent regions in the troposphere. It is known that forward scatter probes would have increased sensitivity and range in detecting the weak refractive irregularities associated with upper tropospheric turbulence. However, additional scatter mechanisms potentially stronger than the weak incoherent backscatter from refractively turbulent regions may exist in the forward scatter system. These are related to the specular and quasispecular scatter associated with relatively stable strata, and scattering from these regions may result in signal levels which can mask contributions originating from turbulent regions. In this paper, we compare the expected received power arising from the scattering from high altitude turbulent layers, intersected with the antenna main beams and that arising from either quasispecular and/or diffuse scattering from lower tropospheric regions intersected by the sidelobes of the antenna. The scattering from the lower troposphere is the sum contribution of all sub volumes of main beam--sidelobe intersections which are here determined using the prediction methods outlined in N.B.S. Technical Note 101. The scattering from turbulent high altitude layers is computed under the assumption that isotropic homogeneous turbulence as predicted by equilibrium theory exists. Dependence of relative signal strengths upon station separation, layer heights, and frequency are presented for an assumed antenna model.

II. 5-2 INITIAL EXPERIMENTAL DATA FROM THE VALLEY-FORGE WALLOPS ISLAND TROPOSCATTER PROBE. Richard J. Doviak, Julius Goldhirsh, Albert Miller, The Moore School of Electrical Engineering, Univeristy of Pennsylvania, Philadelphia, Pennsylvania

A forward scattering experiment incorporating the use of a high resolution, pulsed, S-band radar system operated by the Moore

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School of Electrical Engineering, University of Pennsylvania and the Joint Air Force NASA facility (JAFNA) at WAllops Island, Virginia is described and some initial results of the experiment are given.

The initial data demonstrates the importance of a forward scatter probe system possessing simultaneous spatial as well as time resolution for the purpose of resolving more accurately the main beams' common volume as well as distinguishing signals received via the side lobes. The achievement of spatial beam resolution is here obtained utilizing 50 and 60 foot diameter antenna dishes at the transmitting and receiving sites, respectively, and the achievement of time resolution is obtained by synchronizing the stations establishing a mutually known reference time and utilizing narrow pulses.

Specifically, the initial results of the experiment have demonstrated the following:

(a) The feasibility of phase locking the pulse repetition frequency at both stations using Loran-C pulse transmissions.

(b) The capability of establishing a mutually known reference time via low altitude scattering or ducting between the sites.

(c) The capability of obtaining variable beam angle-time delay signatures, depicting layer scattering using an oscilloscope presentation.

The accuracy and time stability involved in locking both stations and achieving a mutually known reference time are here described. Typical signatures of the type described in (c) are presented, and through a subsequent analysis, the location and spatial extent of the atmospheric layers are characterized.

II. 5-3 RADIOMETEOROLOGICAL INTERPRETATIONS OF TROPOSCATTER TIME DEPENDENCE OVER A MOUNTAINOUS PATH. D. A. Rogers, H. M. Swarm, Department of Electrical Engineering, University of Washington, Seattle, Washington., L. B. Craine, Department of Electrical Engineering, Washington State University, Pullman, Washington

Since 1967 troposcatter data has been collected on a 411 kilometer

Seattle-Pullman (Washington) path using an existing beam-rotating F.A.A. radar transmitter as the signal source. In early 1970 similar data was collected simultaneously over a Spokane-Seattle path. Long term envelope fluctuations with apparent periodicities of 0.08 to 1.25 cycles per minute have been observed on both paths. This may indicate the existence of large scale, periodic changes in the index of refraction fluctuation. These envelope fluctuations are only rarely correlated with the maximum upper air wind velocity. However, short term envelope fluctuations are highly correlated with wind velocity. Large aircraft in the common volume have been found to be the source of most of the higher observed signal levels. Some signal anomalies were apparent during the March 7, 1970, solar eclipse and some direct eclipse effect may have been observed.

The entire system including a model of the atmosphere has been simulated successfully on a digital computer. The simulation programs allow detailed studies of the effects of instrumentation and atmospheric parameters. Of special interest is that even a relatively simple model atmosphere will give rise to very large amplitude fluctuations.

The study supports the claims of other investigators that a bistatic approach in the probing of the troposphere is extremely useful.

II. 5-4 FINE STRUCTURE OF THERMALLY STABLE LAYERS OBSERVED BY HIGH RESOLUTION RADAR. Douglas R. Jensen, Earl E. Gossard, Juergen H. Richter, Propagation Technology Division, Naval Electronics Laboratory Center, San Diego, California

A high resolution radar developed at the Naval Electronics Laboratory Center by J. H. Richter is used in this paper to study the fine structure of the lower troposphere. The radar revels the presence of multiple layers of what appears to be small scale turbulence within temperature inversions which are capable of producing the radar backscatter. These layers reveal a complex internal wave structure. The theory of the formation and maintenance of such layers is discussed and compared with observation.

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II. 5-5 LABORATORY INVESTIGATION INTO EVALUATION OF APERTURE-TO-MEDIUM COUPLING LOSS. D. F. Rost, R. E. Post, Electrical Engineering Department and Engineering Research Institute, Iowa State University, Ames, Iowa

Aperture-to-medium coupling loss is the term applied to the inability of large antennas to realize their full plane-wave gain when used in tropospheric radio wave propagation circuits. Analytic investigation by several authors has resulted in widely divergent theories. Previous experimental results have not been successful in confirming or denying any of those theories or solving the problem emperically as the experimentally determined values showed little correlation.

This paper describes a system capable of investigating the question of aperture-to-medium coupling loss in the controlled environment of the laboratory. Though not precisely a model, strong use was made of a length scale factor of 1.16×10^6 and obvious similarities between the tropospheric propagation paths and the scatter propagation path developed for the setup. A helium-neon laser provided a high frequency, monochromatic, coherent source of high intensity. The propagation path was a narrow scattering media of spherical glass beads over a large, spherically-ground disc of glass. The transmitter and receiver were circular apertures. A photographic technique was developed to allow numerical evaluation of the power available at the receiver.

Changes in aperture sizes caused an incremental aperture-to-medium coupling loss which was independent of the path distance and was described by $18|\log_{10}$ Diameter of transmitter/Diameter of receiver$|^{2.50}$. A distance-induced incremental aperture-to-medium coupling loss (commonly referred to as range attenuation) was found to be 0.092 db per km when referred to an earth-sized range.

II. 5-6 TROPOSPHERIC PROPAGATION WITH AN ELEVATED LAYER. Irvin H. Gerks, 2725 Meadowbrook Drive, S. E., Cedar Rapids, Iowa

In this analysis, the atmosphere is assumed to be stratified, with horizontal variations neglected. The refractive modulus is represented by a linear profile except for a transition within the layer, where two parabolic segments are used to represent a decrease of refractive modulus. With such a profile, the solutions of the differential equation as a function of height are Airy functions for the linear segments and Whittaker functions for the parabolic segments of the profile. The eigenvalues of the solution are determined by solving a set of simultaneous equations which specify continuity of the solution and its first derivative at the various boundaries where the profile segments are joined.

Computer solutions have been generated for the case where the wavelength is 0.3 m and where the layer is 100 m thick and the surface excess of refractive modulus is 30 N units. The height of the layer is varied, and the attenuation, phase shift, and height-gain function are investigated for the first two normal modes. For the conditions chosen, the attenuation vanishes as the height of the layer increases, but the coupling between low antennas becomes poorer. The variation of height is depicted for antenna heights of 5, 10, 15 and 20 meters. For larger values of layer height, this height gain drops off exponentially. It is suggested that turbulence reduces this loss by improving the coupling of the antenna to the layer.

II. 5-7 CHARACTERISTICS OF FALSE RADAR TARGETS OVER THE SEA DURING ANOMALOUS PROPAGATION CONDITIONS.
T. G. Konrad, J. H. Meyer, The Johns Hopkins Univeristy, Applied Physics Laboratory, Silver Spring, Maryland

False radar targets over the sea resulting from trapping in a strong surface duct have been observed with the Wallops Island radars at X and S band. The targets extended roughly a hundred n.mi. out to sea. RHI and PPI scope photographs taken throughout four and a half hours of observation, show the variability of the anomalous targets in both space and time.

Two distinct types of targets were found, dot like or point targets and diffuse, areal targets which appear streaked and patchy and contain considerable internal structure. At times the patterns of the areal targets were repeated as many as four times on PPI photographs with striking fidelity.

Stepped elevation angle PPIs were made from 0^{o} to 0.75^{o} at 0.25^{o} increments to show the dependence of the returns on elevation angle. In all cases, the returns had completely disappeared by 0.75^{o}.

Attenuation was also added to the received signal. The resulting RHI and PPI photographs show the internal structure in detail.

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The intensity of the signal was recorded from several locations in the first and second 'skip'. These data were used to calculate the probability density, the cumulative probability distributions and the fluctuation spectra of the signal power. At S band, the probability distributions are found to be log-normal. At X band there is a definite tendency towards log-normal but the distributions deviate somewhat in the tails.

The spectra of the fluctuations at both wavelengths appear to follow a power law with an exponent of approximately -3.0.

The characteristics of the false targets are consistent with those from sea clutter at low grazing angles. The set of observations represents a striking example of the effect of a surface duct on radar propagation.

COMMISSION III

ON THE IONOSPHERE

Dr. Erwin Schmerling, Chairman

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WAVE PROPAGATION

John M. Kelso, Chairman

III. 1-1 THE FIELD OF AN INCLINED DIPOLE OVER A SPHERICAL EARTH WITH AN ANISOTROPIC IONOSPHERE.
Richard L. Lewis, Institute for Telecommunication Sciences, ESSA Research Laboratories, Boulder, Colorado

The radial electric field near the earth's surface due to a nearly horizontal dipole antenna is calculated by summing the wave-hop series. Each wave-hop can be evaluated either by a saddle point approximation, appropriate to the lit region, by numerieal integration, appropriate in the vicinity of the caustic, or by summing a wave-hop residue series, appropriate to the shadow region. The radial magnetic field is readily obtained as the dual of the radial electric field.

Each wave-hop is diagrammatically shown to consist of the sum of an upgoing and a downgoing wave. This physical picture clearly identifies the number of reflections experienced at the surface of both the ground and the ionosphere by each wave.

A great simplification in the evaluation of the wave-hop integrals is customarily attained by replacing the ionosphere reflection coefficients by their constant Fresnel equivalents. This has the effect of ignoring some earth detached reflections. The validity of reintroducing these reflection coefficients inside the integrand when the ionosphere is anisotropic is briefly discussed.

The numerical results of this investigation compare the field of a vertical electric dipole with the broadside field of a horizontal electric dipole and with the endfire field of a horizontal electric dipole.

III. 1-2 VLF PROPAGATION PARAMETERS FROM OBSERVATIONS AT SUNRISE AND SUNSET.
S. F. Mahmoud, J. C. Beal, Electrical Engineering Department, Queen's University, Kingston, Ontario, Canada

Observations of VLF signals as a function of distance from the transmitter have been reported by many workers. Such observations require a mobile receiving station. This paper describes a simpler experiment based on a fixed receiving station and making use of the secondary source formed by the moving discontinuity at the shadow line during the transition of sunrise and sunset between the transmitter and receiver.

By means of a computer technique based on parameter optimization using the method of steepest descents, a best fit is obtained, in the least-squares sense, between the observed data on a particular path and the predictions from a theoretical model during the sunrise or sunset transition. As well as yielding new data on the attenuation and phase-change coefficients of the various waveguide modes, information is obtained on the mode excitation factors and the scattering parameters of the shadow line discontinuity. The results indicate that a 2-night modes / 2-day modes model is necessary for adequate explanation of the observed data. The corresponding field from Crombie's suggested model [1], (2-N modes / 1-D mode), constitutes only one component of the total received field. The additional component, the second day mode, attenuates faster than the first, but it cannot be neglected, especially at early times during sunrise.

The authors wish to acknowledge the assistance and encouragement received form Dr. J. S. Belrose of the Communications Research Centre, Ottawa, Canada.

[1] D. D. Crombie: "Periodic Fading of VLF Signals Received Over Long Paths During Sunrise and Sunset", Radio Science (Jour. Res. NBS), Vol. 68D, pp. 27-34, January 1964.

III. 1-3 EXCITATION OF THE TERRESTRIAL WAVEGUIDE BY SOURCES IN THE LOWER INONSPHERE. Janis Galejs, Sylvania Electronic Systems Eastern Division, Sylvania Electric Products Inc., Needham Heights, Massachusetts.

Data on field penetration in the ionosphere are used in conjunction with the appropriate reciprocity relations to determine the effectiveness of dipole sources within the ionosphere relative to sources near the surface of the earth. In this formulation the orientation of the magnetic or electric dipole sources, the direction of the geomagnetic fields and the direction of propagation below the ionosphere are arbitrary; ionospheric stratifications and curvature of the geometry is allowed for.

Electric dipoles oriented along the direction of the geomagnetic field are ineffective exciters of the terrestrial waveguide, and a transverse orientation is preferable. For magnetic dipoles the transverse orientation is also preferable, but the fields of an axial orientation are of the same order of magnitude. An effective penetration to the earth-to-ionosphere cavity requires dip angles of the geomagnetic field in excess of 15 to 20°. Under nighttime conditions VLF TE modes are excited more effectively for West-to-East direction of propagation and the TM modes - for East-to-West direction. During daytime ionospheric sources excite TE modes more effectively than groundbased sources; still TM modes appear to dominate. The effectiveness of a ionospheric source is about 10% at nighttime and 1% at daytime relative to groundbased sources of same dipole moment in the VLF range.

In the ELF range the relative effectiveness is from 20 to 100%. During nighttime the largest efficiencies are observed under conditions when strong terrestrial fields are observed near the F-layer or when the terrestrial waves are highly attenuated.

III. 1-4 POLARIZATION AND MULTIPATH EFFECTS ON COMMUNICATION OVER A SHORT RANGE HIGH FREQUENCY LINK. Jefferson F. Lindsey, T. N. Whitaker, University of Houston, Houston, Texas

Extensive measurements have been made between the University of Houston Camp Wallace facility near Alta Loma, Texas and the University of Houston in Houston, Texas with a baseline distance of 46.5 kilometers (29 miles). Measurements of the signal received at the University of Houston on 8 MHz were obtained using two orthogonally oriented-horizontal dipoles each connected to a separate receiver. A common local oscillator was used to permit phase comparison at the receiver intermediate frequency outputs with an oscilloscope. Two types of signals were transmitted - first a continuous wave (c.w.) and then on-off keying with an on-time of 50 microseconds and a repetition rate of 20 turn-ons per second. Amplitude fading was observed in the c.w. case on both receivers and found to exhibit peak-null patterns as a function of time which were out- of - phase during approximately half of a 15 minute period. This led to the conclusion that some polarization rotation was occurring. The rates of rotation varied from 2 to 49 for a 5 minute period. It was found that the polarization varied between predominately linear and predominately circular for approximate 15 minute intervals. Amplitude variations typically ranged between 3 and 24 dB. The pulse measurements showed as many as four incoming pulses spaced 1300-1400 microseconds apart. By observing the oscilloscope it was found that each pulse had a different polarization character.

III. 1-5 RESONANT WAVE-WAVE INTERACTION AS A POSSIBLE CAUSE OF DUCTING OF EM WAVES IN THE MAGNETOSPHERE. K. C. Yeh, C. H. Liu, Ionosphere Radio Laboratory, Department of Electrical Engineering, University of Illinois at Champaign-Urbana

Resonant wave-wave interaction among one ion acoustic wave and two electromagnetic waves in a plasma is studied. The emphasis is on the possibility of trapping of the electromagnetic waves. Equations for the three-wave system are derived. A particular case of interest for which the frequency of the ion acoustic wave is much less than the frequency of the electromagnetic waves is studied in detail. For this case, it is shown that energy exchange takes place only between the two high frequency waves while the ion acoustic wave acts only as a kind of catalyst for the interaction. Simple solutions are obtained for the three waves. It is found that due to interaction, the electromagnetic energy is trapped within a certain spatial region. The trapping width is found to depend, among other parameters, on the magnitude of the ion acoustic wave. Extension of the theory for the case of magnetoplasma will be described. Possible application of the theory to topside ionospheric observations of the field-aligned propagation will be discussed.

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THE DISTURBED IONOSPHERE

Thomas A. Seliga, Chairman

III. 2-1 RAPID VARIATIONS IN POLAR CAP ABSORPTION.
Irving Chidsey, U. S. Army Aberdeen Research & Development Center, Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland

Signal level and dispersive phase measurements were made at Fort Churchill, Canada, using rocket borne radio frequency beacons during the November 2, 1969 Polar Cap Absorption event. Received signal levels varied rapidly during the period when the beacon was above 100 km and therefore above the main absorbing region. At 18 MHz the signal level measurements for the rocket above 100 km indicated variations in absorption of ±6 db about a mean of 18 db with concordant variations at 37 and 73 MHz. The corresponding dispersive phase measurements indicated that the electron content varied about its mean value by $\pm$ 3.5 x 10^{14} electrons per square meter column. This is equivalent to 10% of the electron content below the peak altitude of 119 km, 50% of the content below 86 km or the total content below 76 km.

Features as short as 3 seconds were observed to occur simultaneously on all three signal level records and also in the dispersive phase measurements. The most notable feature was a 6 db drop in absorption at 18 MHz. This lasted for 30 seconds and was accompanied by a decrease in the electron content of 2.5 x 10^{14} electrons per square meter column. Proportional changes in absorption were observed for frequencies of 37 and 73 MHz.

III. 2-2 LOCAL EFFECTS UPON SCHUMANN (ELF) RESONANCE SPECTRA DURING THE SOLAR ECLIPSE OF MARCH 7, 1970. T. J. Keefe, C. Polk, University of Rhode Island, Kingston, Rhode Island

On March 7, 1970 a nearly total (97 percent) solar eclipse occured over the ELF receiving site near Kingston, Rhode Island. Nearly continuous magnetic field records for the period March 5 to March 10 were therefore subjected to power spectrum analysis to establish whether the local ionospheric changes at the time of the eclipse produce observable effects upon the Schumann spectrum between 3 and 25 Hz. Spectra for the same time of day on all six days were compared; in particular power spectra averaged over adjacent 17 minute periods were obtained with a resolution of .125 Hz. The object of this comparison was to show (a), whether or not any diurnal variation appeared on the day of the eclipse which was not present on the preceding and following days and (b), whether spectral changes noted during the eclipse were similar to those appearing during sunset or sunrise.

All data analyzed show a clear, relatively high Q first resonance near 8 Hz. On most spectra during this time period the second resonance of the East-West H component is relatively broad and line splitting occurs not infrequently, particularly during sunrise and sunset hours. Comparison of the period 1348 to 1524 EST among all six days shows, however, unusually pronounced and wide (2 Hz) line splitting of the second resonance only on the day of the eclipse and particularly during the period 1420 to 1437 EST approximately one half hour after near-totality (1344 to 1346) at the receiving site. Examination of the time sequence of observations such as VLF phase advance, riometer data and particle counts characterizing a PCA event which began probably at 1410 UT on March 6 (0910 EST) indicates that it cannot account for the changes in the ELF spectrum observed during the solar eclipse period.

Some consideration is given to ideas accounting for the appearance of line splitting primarily in the vicinty of ionospheric discontinuities, such as those caused by the eclipse or by sunrise and sunset, rather than in the entire cavity.

III. 2-3 ELECTRON CONCENTRATION PROFILES FOR PCA EVENTS.

W. Swider, T. J. Keneshea, Air Force Cambridge Research Laboratories, Bedford, Massachusetts

Electron concentrations versus time are computed for a D-region ionized by precipitating protons. Detachment processes do not appear to be prominent at night. Previously we have suggested that near 80 km H_2 or H might react with O_2^- detaching its excess electron. However, the midnight atomic oxygen concentration of Shimazaki and Laird (J. Geophys. Res., June, 1968) would make $O + O_2^- \rightarrow O_3 + e$ more important. Comparison of the calculations with a nighttime measurement by J. C. Ulwick of electron concentrations during the November, 1968, PCA event indicates detachment processes are absent below about 80 km where Shimazaki and Laird find atomic oxygen declines sharply. In the daytime, detachment reactions of O_2^- with O and $O_2(^1\Delta)$ are shown to proceed at a rate exceeding that for photodetachment, as suggested by others. Atomic oxygen is the major detachment agent down to about 65 km with $O_2(^1\Delta)$ being important from 65-50 km. The rate of O_2^- formation swamps the detachment processes at 40 km, thereby limiting the electron concentration to less than 1 cm^{-3}. The lifetime of $O_2(^1\Delta)$ is 10 minutes at 65 km and 16 minutes at 70 km and may contribute to the "hysteresis effect" seen in riometer absorption. The abundance of the minor constituent NO_2 is seen to have a major bearing on the daytime electron concentration profile.

III. 2-4 IONOSPHERIC OSCILLATIONS GENERATED BY THUNDERSTORMS. D. G. Detert, C. A. Moo, Avco Corporation, Lowell, Massachusetts, A. D. Pierce, Massachusetts Institute of Technology, Cambridge, Massachusetts

Experimental evidence is presented which extends and supplements that recently reported by Georges and by Baker and Davies concerning the characteristic infrasonic oscillations of the ionosphere during periods of thunderstorm activity. The observing system consisted of a network of three, short-baseline (approximately 35 km separation), near vertical incidence hf Doppler sounding paths near Huntsville, Alabama, each operating with up to three simultaneous transmission frequencies chosen between 2 and 6 MHz. A spectrum analysis of some typical Doppler perturbations indicates periods between 2 and 5 minutes are present. These oscillations appear coherent over the sounding area and ionospheric heights, frequently for many hours duration, consistent with their interpretation as acoustic waves of very long wavelength (roughly 150 km for 3.5 minute period waves in the lower ionosphere). The fact that the observed periods are somewhat lower than the usually accepted values (typically, 9 minutes) of the Brunt-Vaisala period for the troposphere is explained by a detailed rederivation of the natural buoyancy period including the presence of water vapor.

III. 2-5 OBSERVATIONS OF D-REGION ELECTRON DENSITY DURING SOLAR FLARES. J. N. Rowe, A. J. Ferraro, H. S. Lee, Ionosphere Research Laboratory, The Pennsylvania State University, University Park, Pennsylvania, A. P. Mitra, National Physical Laboratory, New Delhi, India

In this paper electron density and production rate changes measured during 5 solar flares are analyzed to provide information on the height distribution of nitric oxide and on the electron loss rate in the D-region. The electron densities were measured by the wave interaction technique at The Pennsylvania State University, and the electron production rate due to x-rays was calculated from the 0.5 -3Å and 1 -8Å flux measured by SOLRAD 9.

In the range 65 - 80 kilometers the NO density was found to be between 10^7 - 10^8 cm^{-3}, in general agreement with the experimentally determined rocket values of Meira.

Evidence is presented to show that the electron loss rate must decrease during a solar flare at heights of 80 km and lower.

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AERONOMY

Erwin R. Schmerling, Chairman

III. 3-1 SEASONAL VARIATION OF O/N_2 IN THE F1 REGION.

L. P. Cox, J. V. Evans, M.I.T. Lincoln Laboratory, Lexington, Massachusetts

Measurements are presented of the ratio of O^+ ions to molecular ions $[O_2^+ + NO^+]$ at F1 region altitudes during 1968 and 1969 obtained with the Millstone Hill L-band incoherent scatter radar. In order to obtain these estimates it was necessary to adopt a model for the altitude variation of either the ion or electron temperature T_i (or T_e). Here we assumed that the ion temperature followed the neutral temperature over the altitude range 120-200 km and was given by

$$T_i = T_n = T_\infty - (T_\infty - T_{136}) \exp- [.028(h-136)]$$

where h is the height in km, T_∞ is the exospheric neutral temperature derived from incoherent scatter measurements of electron density, electron and ion temperature in the F2 region, and T_{136} is the ion temperature observed at 136 km assuming only molecular ions are present at this altitude.

Employing these measurements of composition, together with measurements of electron density, we have computed the ratio of O/N_2 at 200 km at noon employing solar fluxes published by Hinterreger. The results show a pronounced seasonal variation, the relative abundance changing by a factor of two between summer and winter. This seasonal variation is thought to be the cause of the seasonal anomaly in f_oF2, and be produced by global transport of O from the summer to winter hemisphere.

III. 3-2 UPPER F2 REGION VERTICAL FLUXES OF O^+ AND H^+.*

J. V. Evans, T. Hagfors, M.I.T. Lincoln Laboratory, Lexington, Massachusetts

Oxygen and hydrogen ions in the upper F2 region assume different vertical drift velocities through the charge exchange region owing to the variation of their relative abundance with altitude. Calculations have been carried out to explore the consequences of this on the 'drift velocity' observed by the Millstone Hill

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

incoherent scatter radar for a wide range of relative abundances and velocities. We find that where the O^+ abundance is $\geq$ 50% the measured drift velocity corresponds closely to the O^+ velocity. It follows that there is a region over which the incoherent scatter measurements of electron density and drift velocity yield the vertical flux of O^+. Above about 600 km any variation of this flux with altitude may reasonably be attributed to an unobserved flux of H^+ since charge must be conserved. Thus, the measurements can be made to yield the vertical fluxes of O^+ and H^+ in the transition region, and from these the altitude variation of the proton concentration may be determined. Results are presented for a number of days for which this type of analysis has been carried out.

III. 3-3 QUASI-PERIODIC FLUCTUATIONS IN THE NIGHTTIME F REGION. T. F. Trost, Arecibo Observatory, Arecibo, Puerto, Rico

Observations by incoherent-scatter radar reveal quasi-periodic fluctuations in electron density as a common feature of the nighttime F region. The radar is operated at vertical incidence and probes up to an altitude of 550 km. The range of fluctuation periods that can be measured is 0.5 minutes to about 40 minutes. Often the fluctuations observed have well-defined periods and vertical structure extending up to the altitude limit of the measurement. The most frequently occurring periods lie in the range 5-18 minutes, and the least frequent are between 20 and 28 minutes. Fluctuations at more than one period are often observed simultaneously in the range less than 20 minutes. At times the phase is approximately the same at all altitudes, indicating an alternate increase and decrease in electron density at all points along the beam. The perturbation in electron density varies with altitude and is typically 5 - 15%. An acoustic-wave interpretation may be adequate to explain these results. For the fluctuations with periods greater than 28 minutes the phase is found to vary with altitude in a manner consistent with the forward tilting of phase fronts expected for gravity waves.

III. 3-4 AN IONOSPHERIC E REGION NIGHTTIME MODEL. W. M. Chen, R. D. Harris, Aeronomy Center, Utah State University, Logan, Utah

A series of five rocket flights were launched from Wallops Island during a six hour period on the morning of 22 February, 1968. Electron density profiles were measured with a Langmuir probe during ascent and glowing vapor was released for wind measurements during descent. Two of the electron density profiles have been theoretically modeled (0300 and 0602 local time), using ion chemistry appropriate to the E region, standard neutral atmosphere, and wind transport terms based on the measured wind values. A nighttime ionization source consisting of scattered geocoronal Lyman alpha and Lyman beta radiation was assumed. Theoretical molecular ion density profiles were calculated and compared with the measured electron density curves.

At 0300 the theoretical and measured profiles differed by less than a factor of two. The necessity for metallic ions in the formation of thin layers in the E region is demonstrated in this ionization profile. The 0602 ionization profile (98° zenith angle) has the shape of the measured profile, but the level of ionization is a factor of three too low. Calculations indicate that additional production of NO^+ is required over the nighttime value. This increased ion production is likely due to ionization of NO by Lyman alpha. Both models show the importance of wind transport terms and a nighttime ionization source in E region ionization profiles.

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SPECIAL TOPICS

Anthony J. Ferraro, Chairman

III. 4-1 THE MEANING OF A COMPLEX GROUP REFRACTIVE INDEX.
R. Michael Jones, Institute for Telecommunication Sciences, ESSA Research Laboratories, Boulder, Colorado

As is well known, difficulties arise in calculating the group velocity in a lossy medium, because the group refractive index is a complex number. A simple calculation clears up the difficulties and gives meaning to a complex group path. Using the saddlepoint approximation to calculate the time response of the ionosphere to a time-harmonic radio wave modulated by a Gaussian-shaped pulse leads to the following results: (1) a simple formula for time focusing, (2) the dominant frequency of the returned pulse is shifted from that of the transmitted pulse by an amount proportional to the imaginary part of the group path, and (3) as might be expected, the time delay of the pulse maximum is given by the real part of the complex group path.

III. 4-2 UHF RADAR OBSERVATIONS OF AURORAL BACKSCATTER.
J. C. Ghiloni, Jr., Bell Telephone Laboratories, Inc., Whippany, New Jersey

The characteristics of backscatter from the radio aurora have been determined from radar observations made at the Prince Albert Radar Laboratory, Prince Albert, Saskatchewan. This 448 MHz radar scanned a region from 320° to 60° in azimuth and from 0° to 12° in elevation. 1270 such scans were made during the period March through November, 1968, and auroral echoes were detected on 474 of them. An analysis of doppler data has shown that the motion of the scatterers undergoes a reversal in direction about three hours before local magnetic midnight. In the afternoon the echoes had predominantly approaching velocities east of magnetic north and receding velocities west of magnetic north. Whereas echoes detected in the morning were receding towards the east and approaching from the west. If the scatterers are assumed to move in the same direction as the electrons, these observations suggest that the E-region currents are directed eastward in the afternoon and westward in the late evening and early morning. Data is also presented on the statistics of echo

occurrence and intensity. The echoes were found to be highly aspect sensitive. The variation of echo occurrence and southernmost extent with K_p and time of day were found consistent with the concept of an auroral oval.

III. 4-3 RAY TRACING PREDICTIONS OF IONIZATION TROUGH EFFECTS UPON HIGH FREQUENCY RADIO WAVES.
Allan D. Thompson, Ward J. Helms, Department of Electrical Engineering, University of Washington, Seattle, Washington

This paper is concerned with the effects of ionization troughs occurring in the ionosphere on the propagation of high frequency radio waves. Large scale systematic electron density reductions in the ionosphere have been observed at approximately 60° geomagnetic lattitude by several experimental techniques. This paper makes use of a three-dimensional ray tracing computer routine to simulate effects of such troughs on high frequency radio waves. In particular, examples of trough effects upon ray path trajectories, doppler frequency shift, wave focusing and defocusing, vertical ionograms and ionospheric attenuation are predicted. These examples are presented as a function of trough-transmitter separations, frequency, trough depression magnitude, and direction of propagation. Brief discussions covering the more important features of the trough and the analysis technique are also included.

III. 4-4 COMPARISON BETWEEN TOPSIDE PLASMA RESONANCE STRUCTURE AND ELECTROSTATIC-WAVE ECHO THEORY.
J. R. McAfee, J. M. Warnock, Aeronomy Laboratory, ESSA Research Laboratories, Boulder, Colorado

Topside sounders differ from ground-based sounders by their location within the plasma. Thus, in addition to electromagnetic-wave echoes, many other responses are observed. The most frequent and predictable of these are long, nearly continuous responses, called resonances, that occur at sounding frequencies close to either the plasma, upper hybrid, or electron-cyclotron harmonic frequencies of the ambient plasma. These plasma resonances are electrostatic-wave echoes with delays so extremely sensitive to frequency that a single transmitted pulse has sufficient bandwidth to give echoes with delays ranging over an entire listening time. Thus, a long continuous response is produced.

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Under certain conditions, two echoes at slightly different frequencies are simultaneously detected; therefore, the amplitude of the recorded signal shows a beat pattern between the two waves. A clear example of this beat pattern was recorded by the ISIS-1 sounder on 5 April 1969 at 1027 U. T. while located at 31°S, 67°W, and at 1380 km height. The period of this beat pattern is measured and compared with the period derived from ray-tracing calculations of electrostatic-wave echoes. Good agreement between theory and observations is found for electron temperatures between 4000 and 5000°K. This agreement supports the electrostatic-wave echo theory, and suggests use of propagation experiments as an electron temperature diagnostic.

III. 4-5 RELATIVE IMPORTANCE OF ALFVÉN AND THERMAL VELOCITY DISTRIBUTIONS CORRELATED WITH THE ELF ACTIVITY AND PLASMA HEATING IN THE MAGNETOSPHERE. H. Kikuchi, NRC/NASA Resident Research Associate, Goddard Space Flight Center, Greenbelt, Maryland

Based on OGO-3 and -5 plasma and magnetic field data, the Alfvén, thermal and sound velocity distributions in the magnetosphere are examined and a tentative model typical of undisturbed altitude profies is constructed together with some distinct modifications in this model under different conditions of local time and magnetic activity. Significant is the Alfvén velocity profile in the form of 'hump' at the plasmapause, intersecting with the electron thermal velocity profile at many times near the plasmapause before the Alfvén velocity falls down well below the electron thermal velocity and approaches the sound velocity with increasing altitude. Another distinct feature is an occasional abrupt increase beyond the plasmapause in the ion thermal velocity which becomes comparable or even exceeds the Alfvén velocity near and beyond the magnetopause. These Alfvén and thermal plasma irregularities and their mutual interactions near the plasmapause and near the magnetopause provide possible sources or locations for: geomagnetic pulsations and ELF noises with appropriate instability conditions; plasmapause-trough heating due to electron Landau damping of the magnetosonic waves and due to ion cyclotron damping of the Alfvén wave; magnetopause-sheath heating due to ion Landau and cyclotron damping of the Alfvén and magnetosonic waves. There is a good correlation between this model and observations of geomagnetic pulsations, ELF noises, mid-latitude red arcs and plasma heating.

COMMISSION VI

RADIO WAVES AND TRANSMISSION INFORMATION

Dr. Leopold B. Felsen, Chairman

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DIFFRACTION

R. G. Kouyoumjian, Chairman

VI. 1-1 DIFFRACTION COEFFICIENTS AND ATTENUATION CONSTANTS FOR CONVEX SURFACES. D. R. Voltmer, Department of Electrical Engineering, Pennsylvania State University, University Park, Pennsylvania, R. G. Kouyoumjian, Electro-Science Laboratory, Department of Electrical Engineering, The Ohio State University, Columbus, Ohio

Keller has given first order expressions for the diffraction coefficients and attenuation constants of convex surfaces. In this paper second order terms are presented for the hard and soft surfaces of acoustics and for the perfectly-conducting surface. For surfaces of constant curvature, the diffraction coefficients and attenuation constants are found by retaining higher order terms in the asymptotic solutions of the plane wave diffraction by cylinders and spheres. Then the plane wave diffraction by a more general convex surface is considered, and the work of Hong[1] is used and extended to obtain the diffraction coefficients and attenuation constants for surfaces of variable curvature; these are shown to reduce to the results obtained for the cylindrical and spherical surfaces. The diffraction coefficients and attenuation constants are applied to the diffraction of plane waves by surfaces of constant curvature and by surfaces of variable curvature in the form of the hard, soft, and perfectly-conducting spheroids. The second order terms substantially improve the accuracy of the calculated scattered fields. In the examples considered, the low frequency limitations and the aspect limitations in the calculation of bistatic scattering are imposed by the reflected component of the field. The diffracted field at axial caustics is found from an integral representation of the field,where the equivalent sources are determined by the geometrical theory of diffraction.

1. S. Hong, "Asymptotic Theory of Electromagnetic and Acoustic Diffraction by Smooth Convex Surfaces of Variable Curvature," Journal of Math. Phys., vol. 8, no. 6, pp. 1223-1232; June 1967.

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VI. 1-2 FORWARD SCATTERING BY CONE-SPHERICAL BODIES.
S. E. Stone, F. B. Sleator, Conductron Corporation, Ann Arbor, Michigan

We consider a two or three-dimensional cone-sphere (termination radius a, half cone angle α), with continuous tangent but discontinuous curvature at the join, upon which a high frequency ($ka >> 1$) plane wave is incident nose-on. We study the leading Fock correction to classical diffraction theory in the forward direction for both the far field and Fresnel regions.

Since no exact contour integral representations of the various fields are available, we first find the surface field (or current) on a canonical body. For a Neumann boundary condition, an asymptotic representation of the surface field which is valid if $(ka)^{1/3}\alpha << 1$ (small cone angles) has been found for a two-dimensional canonical body and also extended to three dimensions by Hong and Weston (1966). We employ their method to find the corresponding results for a Dirichlet boundary condition.

We use the above surface fields together with Green's theorem to obtain integral representations for the leading Fock corrections. (c.f. Van De Hulst, 1957, Section 17.23). These integrals are evaluated by residues; the results are applied to finding total scattering cross sections.

For the case $(ka)^{1/3}\alpha >> 1$, we formally show that the leading Fock corrections become those of the corresponding circular cylinder or sphere.

Hong, S. and Weston, V. H., (1966), "A Modified Fock Function for the Distribution of Currents in the Penumbra Region with Discontinuity in Curvature", Rad. Sci., Vol. 1, No. 9, Sept., 1045-1053.
Van De Hulst, H. C., (1957), Light Scattering by Small Particles, John Wiley and Sons, Inc., New York.

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VI. 1-3 BACKSCATTERING FROM A FINITE CONE , E. F. Knott, T.B.A. Senior, P.L.E. Uslenghi, Radiation Laboratory, Department of Electrical Engineering, The University of Michigan, Ann Arbor,Michigan

The theoretical determination of the backscattering behavior of a perfectly conducting right circular cone is still a problem of some interest, particularly in the resonance region and at high frequencies (ka >> 1, where k is the wave number and a is the base radius). Using theory of diffraction (GTD), Keller (1960) derived first order expressions for the backscattering cross section, and Ross (1967) has sought a matching of these results between the wide angle and on-axis (caustic) regions.

Whereas Ross's correction formula was valid only for cones of relatively small included angle, 2γ, we have now obtained a result which is uniform in γ and is consistent with Ufimtsev's work for a disk. Using an empirical factor to describe the transition across the backward cone angle, we have derived a single (first order) formula for the backscattered field applicable to all angles of incidence from axial to specular. We have also determined the second order corrections attributable to cross-base interactions that are directly analogous to those for a disk (Knott, et al, 1970), and have incorporated these effects in the general formula. Values computed using this formula are in good agreement with experimental data for the direct and cross polarized returns, and some comparisons are given.

References:
Keller, J.B. (1960), IRE Trans. AP-8,pp. 175-182.

Ross, R.A. (1969), Cornell Aeroanutical Laboratory Report No. AFAL-TR-67-343.

Knott, E.F., T.B.A. Senior and P.L.E. Uslenghi, (1970), "High Frequency Backscattering from a Metallic Disk (submitted to IEEE, G-AP).

VI. 1-4 INVERSE SCATTERING FOR THE THREE-DIMENSIONAL VECTOR CASE W. A. Imbriale, TRW Systems Group, Redondo Beach, California

This paper describes a method for determining the size, shape, and location of a perfectly conducting scatterer from the knowledge of the incident field and either the scattered tangential fields over a closed surface, or the field components and all their derivatives at a single point. From this data, a multipole field expansion is obtained which converges only outside the smallest sphere enclosing the scatterer. From this basic expansion, an analytic continuation procedure is used to generate the fields in the neighborhood of the scatterer. The geometry of the body is then determined by locating a closed surface for which the total tangential electric field, i.e., sum of the tangential components of the incident and scattered field, is zero. Of fundamental importance is the separation of the tangential field components from the total field. The separation is accomplished based on the following observation: If a sphere encloses a smooth body and intersects it at one and only one point, then at that point the body and the sphere share the same tangent plane.

For the case of a sphere, it is demonstrated analytically that the procedure gives the correct results. Although the technique is theoretically applicable to scatterers of any size, practically speaking its application is limited to objects on the order of a few square wavelengths or less. Several numerical examples of bodies reconstructed utilizing scattered far field data are presented.

VI. 1-5 VLF MODE SCATTERING AT AN ARBITRARY STEP TRANSITION IN IONOSPHERE, A. Rudzitis, The Boeing Company, Seattle, Washington, A. Ishimaru, University of Washington, Seattle, Washington

VLF mode conversion and reflection in a nonuniform curved terrestrial waveguide is investigated. An abrupt step change in reflecting height and surface impedance of the ionosphere represents the transition between the night and day sections of the waveguide. This problem has been studied by Wait and others who derived mode scattering coefficients by neglecting the reflections and by matching the vertical electric field in the aperture. However, in cases where the step size is large the reflected fields may become significant. The purpose of this work is to obtain rigorous solution to the problem of an arbitrary step discontinuity and to investigate the significance of varying surface impedance of the step.

The problem is solved by means of the Wiener-Hopf method. In addition to the roots of two modal equations, roots of a transcendental equation corresponding to the difference in heights between the two waveguides are required. Numerical computations

for cases in which the first few modes are dominant confirm Wait's published results. However, for low frequencies or for cases where higher order modes are important, the analysis of this paper is necessary. As predicted by Wait, the reflection coefficients of modes in daytime waveguides are small. The modes reflected from night-to-day transition are influenced by a surface impedance of step so that the reflected wave may contribute significantly to the total field in the nighttime section.

VI. 1-6 LOCAL PROPERTIES OF EVANESCENT FIELDS*

H. L. Bertoni, L. Levey, L. B. Felsen,
Electrophysics Department, Polytechnic Institute
of Brooklyn, Farmingdale, New York

For the study of the interaction of high frequency evanescent fields with scattering objects or structural inhomogeneities, it is desirable to understand their local and sequential propagation properties, in analogy to those described by ray optics for propagating fields. Selected for discussion are evanescent fields associated with total internal reflection and with caustics produced by converging waves.

Two considerations are relevant: 1) local description of the actual field in terms of a simpler prototype field, and 2) determination of the spatial volume required for sustaining the local field along a propagation path. These aspects are addressed by truncating, or applying a Gaussian modulation to, the actual field distribution on a dielectric interface or caustic, calculating the field away from these initial surfaces, and comparing with the prototype field. For the dielectric interface problem, the simplest prototype field is an evanescent plane wave whereas for focusing problems in homogeneous media, it is the field associated with a circular caustic. Ranges of validity of the local field approximation are given and are derived by analytical and graphical means. The presentation emphasizes physical aspects of the propagation mechanism and includes a discussion of complex rays for evanescent field problems.

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VI. 1-7 POLARIZATION DEPENDENCE OF "CREEPING WAVE PULSES".
J. D. DeLorenzo, Sperry Rand Research Center, Sudbury, Massachusetts, B. Granoff, Boston University, Boston, Massachusetts

The object of this paper is to demonstrate that the phenomena of creeping wave pulse propagation on the surface of a perfect conductor is polarization sensitive. Luneberg's jump conditions are used to show that a conducting surface can support a propagating electromagnetic field discontinuity only when an electric field component perpendicular to the surface exists. The application of these conditions to the time domain problem of electromagnetic scattering from an infinite circular cylinder show that an electromagnetic field discontinuity can propagate along the surface for the case when the incident magnetic field vector is parallel to the cylinder axis, but that no such propagation is possible for the case where the incident electric field is parallel to the axis. The exact impulse responses of an infinite circular cylinder for both polarizations are used to show that this polarization sensitivity also applies to the propagation of a short duration, pulse modulated, high frequency wave on the surface. The theory is also verified by new measurements of the regularized impulse response for a finite length, sphere-capped cylinder. Finally, the application of these concepts and results to the currently interesting problem of broadband radar data analysis is discussed.

VI. 1-8 TOROIDAL OPEN-CAVITY RESONATOR MODES IN INHOMOGENEOUS MEDIA.
F. P. Carlson, N. K. Shi, Department of Electrical Engineering, University of Washington, Seattle, Washington

Trapping of electromagnetic waves in a radially inhomogeneous torroidal medium has been investigated. The existence of realizable eigenfunctions and eigenvalues has suggested the existence of bound modes in such geometries.

The refractive index of the medium was assumed to be montonically decreasing in the radial as well as axial direction. The properties of scalar waves that might propagate in the angular direction were investigated. In order to show similarity with other solutions, the mode patterns were expanded in terms of Gaussian-Hermite polynomials in the axial direction. This expansion led to ordinary Bessel functions in a radial propagating domain and Airy functions in the evanescent region. The turning points and wave numbers for azimuthally propagating modes were found for certain approximate cases. The approximations involved required the existence of smoothly varying wave numbers and wave functions in the axial direction. Although this assumption is restrivtive it at least shows the nature of the trapped modes.

The turning points and the azimuthal wave number depend on the axial position and the wave appears to propagate in a spiral fashion around the toroid. The mode shapes are complex and appear to couple to higher and higher ordered modes as propagation occurs.

These geometries are realized in high pressure gas nozzles and suggest the development of the so called Venus machine and optical delay lines.

VI. 1-9 SCATTERING BY ARBITRARY HOMOGENEOUS, ISOTROPIC SPHERES.
Ronold W. P. King, Gordon McKay Laboratory, Harvard University, Cambridge, Massachusesst, Charles W. Harrison, Jr., Sandia Corporation, Albuquerque, New Mexico

Although an analytical solution for the scattering of a plane electromagnetic wave by an isotropic homogeneous sphere of radius a characterized by arbitrary values of the scaler constitutive parameters $\sigma = \sigma' + i\sigma''$, $\epsilon = \epsilon' + i\epsilon''$, and μ has been available for many years, a detailed quantitative study for spheres over a wide range of sizes and with material properties associated with imperfect conductors, dielectrics,and cold plasmas does not appear to have been made. With the help of a high speed computer the backward and forward scattered fields have now been investigated in a very general form which permits the representation of scattering cross sections in terms of the loss tangent $p = \sigma_e/\omega\epsilon_e = (\sigma' + \omega\epsilon'') / (\omega\epsilon' - \sigma'')$, and the dimensionless parameters k_0a, β/k_0 and α/β in $ka = (\beta + i\alpha)a = (k_0a)(\beta/k_0)(1 + i\alpha/\beta)$ where k is the complex wave number of the material in the sphere and k_0 is the free-space wave number. Universal graphs for the back-scattering and forward scattering cross sections and the phase of the forward and backward scattered fields have been prepared for values of k_0a in the range from $\pi/2$ to 40, β/k_0 from zero to 40 and α/β from near zero to 50. This includes spheres made of ordinary imperfect dielectrics with $\epsilon_e \geq \epsilon_0$, $\alpha/\beta < 1$; underdense plasmas with $\epsilon_0 \geq \epsilon_e > 0$, $\alpha/\beta < 1$; plasmas at the plasma frequency $\epsilon_e = 0$, $\alpha/\beta = 1$; overdense plasmas with $\epsilon_e < 0$, $\alpha/\beta > 1$; and the limiting case of the perfectly conducting sphere with $\sigma_e = \infty$, $\alpha/\beta = 1$.

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NUMERICAL METHODS

Floyd V. Schultz, Chairman

VI. 2-1 ANALYTICAL AND NUMERICAL STUDIES OF THE RELATIVE CONVERGENCE PHENOMENON ARISING IN THE SOLUTION OF AN INTEGRAL EQUATION BY MOMENT METHOD.

R. Mittra, T. Itoh, and T. S. Li, Antenna Laboratory, University of Illinois, Department of Electrical Engineering, Urbana, Illinois

In a recent paper Lee[1] studied the numerical solution of the integral equation

$$\int_0^b K(x,x')\ \psi(x')\ dx' = f(x),\ 0 < x < b$$

for the iris discontinuity problem in a waveguide, and reported that the moment method of solution exhibits a relative convergence phenomenon. That is, if $\psi(x)$ the unknown, and the known function $g(x)$ are approximated in terms of M-term Fourier series, e.g.,

$$\psi(x) = \sum_{m=1}^{M} C_m \phi_m ,$$

then the best approximation to the true solution is obtained for a critical value of M, say M_c which in turn is dependent on P, the number of terms retained in the series representation for

$$K(x,x') = \sum_{n=1}^{P} Y_n \chi_n(x) \chi_n(x') .$$

For the iris problem, χ_n's are Fourier series basis functions for the range $0 < x < a$, with $a > b$.

An analytical theory is developed in this paper to explain this phenomenon and several other facts that have been revealed from a systematic numerical study of the integral equation for the iris problem. The analytical approach is based upon a formal representation of the solution from which the asymptotic behavior of C_m's are derived for large m. It is shown that whereas the correct algebraic behavior results for the choice $M = M_c$, the higher order coefficients show an exponential growth for $M > M_c$. This theoretical prediction is also supported by the numerical results that are included in the paper. In addition, the numerical study shows that the energy check, which is conventionally employed in numerical solutions of such problems, is entirely unreliable. Furthermore, letting $M > M_c$ is found to have a marked effect on the higher order coefficients C_m for $m > M_c$ and it is suggested that the behavior of these coefficients, rather than that of the discontinuity susceptance, be used as a guide for an optimal choice of M in the numerical solution of integral equations of this type.

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1 S. W. Lee and W. R. Jones, "On the Suppression of Radiation Nulls in Waveguide Phased Arrays", URSI Spring Meeting, Washington, D. C., 1970.

VI. 2-2 COMPUTATION OF GREEN'S FUNCTIONS FOR BODIES OF REVOLUTION. R. F. Harrington, J. R. Mautz, Department of Electrical Engineering, Syracuse University, Syracuse, New York

This study considers the Green's function relating the electric intensity at one point due to a current element at another point in the vicinity of a conducting body of revolution, either loaded or unloaded. The solution is obtained by solving the E field integral equation by the method of moments, and is expressed in terms of generalized network parameters. The program was tested by comparing computations with the known solution for conducting spheres. Sample computations were made for bodies of other shapes, such as disks, cone-spheres, and so on. Radiation patterns for current elements near conducting bodies, both loaded and unloaded, were also computed. The external solution can be used as a subprogram for more complicated problems, such as the analysis of radiation and scattering from antennas and arrays in the vicinity of bodies. The internal solution can be used as a subprogram for more complicated problems, such as the coupling to resonant cavities by loops or probes.

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VI. 2-3 A SPACE-TIME INTEGRAL EQUATION SOLUTION FOR CURRENTS ON WIRE STRUCTURES WITH ARBITRARY EXCITATIONS.

C. L. Bennett, J. Martine, Sperry Rand Research Center, Sudbury, Mass.

A new technique of numerical solution of time domain integral equations is applied to the problem of determining the currents on straight wire scatterers and antennas with arbitrary time dependent excitations. A space-time integral equation for the wire currents is formulated in such a way that it may be reduced to a recurrence relation in time which is well suited for solution on a digital computer. Another advantage of this formulation is that it provides insight into the transient mechanism even before numerical techniques are employed. In particular, this integral equation is cast in a form that specifically displays the wave character of the currents, the effect of the wire ends on the currents, the coupling of the currents to the excitation, and the losses due to radiation.

Results for the wire currents and far fields will be presented and discussed for various wire sizes and excitations. Both the scattering problem and the antenna problem (transmit and receive) will be considered.

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STOCHASTIC ASPECTS OF WAVE PROPAGATION

Robert E. Collin, Chairman

VI. 3-1 A NUMERICAL STUDY OF RAYS IN RANDOM MEDIA.
M. Youakim, C. H. Liu, K. C. Yeh, Ionosphere Radio Laboratory, Department of Electrical Engineering, University of Illinois at Champaign-Urbana

The statistics of the electromagnetic rays in a random medium are studied numerically by the Monte Carlo method. A technique of generating two dimensional random surfaces with prescribed correlation functions will be discussed. These surfaces are used to simulate the random medium. Rays are then traced in these sample media. Statistics of the ray properties such as the ray positions and directions are computed. Histograms showing the distributions of the ray positions and directions at different points along the ray path as well as at given points in space are given. The problem of diffusion of a beam of rays in a random medium is also investigated. The numerical experiments are repeated for the different cases corresponding to weak and strong, isotropic and anisotropic random fluctuations in the refractive index of the medium. Results of these experiments are compared with those derived from theoretical investigations whenever it is possible.

VI. 3-2 MONTE-CARLO COMPUTATIONS FOR ONE-DIMENSIONAL RANDOM MEDIA.* George Bein, Shalom Rosenbaum, Department of Electrophysics, Polytechnic Institute of Brooklyn, Farmingdale, New York

Hochstim and Martens were first to use Monte Carlo computations to study scattering characteristics of scalar waves from randomly fluctuating slabs with an exponential spatial correlation. This presentation describes an alternative procedure which overcomes some of the deficiencies in their treatment and extends the study to physical circumstances which have not been previously considered (e.g., background inhomogeneity, crossover into cutoff regions, etc.)

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* The research reported in this paper was sponsored in part by the Air Force Cambridge Research Laboratories, Office of Aerospace Research, under Contract F19628-68-C-0072, but the report does not necessarily reflect endorsement by the sponsor.

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The two-point correlation function characterizing the medium fluctuations (more directly the spectral density) may be arbitrarily selected and is no longer restricted to an exponential. The correlation properties of the medium are virtually independent of the length of the elementary slabs comprising the overall slab region, whence the medium may be structured by equal-sized slab realizations -- a major advantage whenever a background profile is superimposed. Furthermore, the statistics associated with the reflection and transmission of both the coherent as well as the incoherent waves are calculated separately. The results so obtained yield "exact" solutions with which appropriate analytical theories can be conveniently compared and they provide information additional to that found in previous studies.

VI. 3-3 A NOTE ON THE POLARIZATION PROPERTIES OF STOCHASTIC ELECTROMAGNETIC PLANE WAVES OF ARBITRARY BANDWIDTH. John K. Schindler, Microwave Physics Laboratory, Air Force Cambridge Research Laboratories, Bedford, Massachusetts

Consider a uniform, stochastic electromagnetic plane wave of arbitrary bandwidth and zero mean value. Orthogonal field components selected from a plane perpendicular to the direction of wave propagation are then scalar random processes which have zero mean values but are not necessarily stationary. Two classes of stochastic plane waves will be of importance. First, a plane wave is deterministically polarized when the vector direction of its electric field is known with complete certainty at each instant of time but when its instantaneous magnitude is random. Second, a plane wave is randomly polarized when all correlation properties of the wave are independent of coordinate rotation about the direction of wave propagation. Thus, measurements of any second order statistical moment of a randomly polarized wave are independent of receiving antenna orientation in a plane perpendicular to the direction of wave motion.

We demonstrate that an arbitrary stochastic plane wave can be decomposed uniquely into the superposition of uncorrelated deterministically and randomly polarized components. All space-time correlation properties of the decomposed wave are exactly those of the original plane wave. Further, the instantaneous vector direction of the deterministically polarized component and all correlation properties of both components can be determined uniquely from measurements of the space-time correlation properties of the original wave.

The results presented here are related to those given earlier by Wolf[1] for quasi-monochromatic plane waves. The advantages of the decomposition presented here are that [1] it provides a general representation of all space-time correlation properties of the wave and [2] it is both mathematically and physically reasonable without assumptions regarding the bandwidth of the stochastic plane wave.

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1 Born, M. and E. Wolf (1964), Principles of Optics, Pergamon Press, New York.

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PLASMAS AND PROPAGATION

Raj Mittra, Chairman

VI. 4-1 APERTURE RADIATION FROM A CONDUCTING CYLINDER COATED WITH AN INHOMOGENEOUS AND ANISOTROPIC PLASMA SHEATH. W. C. Wong, TRW Systems Group, Redondo Beach, California; D. K. Cheng, Electrical Engineering Department, Syracuse University, Syracuse, New York

The axial field components in an inhomogeneous and anisotropic plasma sheath due to radiation from an arbitrary aperture on a conducting cylinder are governed by coupled differential equations with variable coefficients. An analytic solution for the most general plasma variation is not possible. When only radial inhomogeneity exists, the solution is facilitated by a stratification technique through the introduction of 4x4 transmission-coefficient matrices. This approach circumvents the need for the solution of a large number of simultaneous equations resulting from matching the boundary conditions at the interfaces of many stratified layers.

This paper presents the complete formulation for obtaining the free-space radiation fields of finite circumferential and axial slots. The fields are in the form of Fourier-Bessel integrals which can be evaluated by noting the locations of the branch points and using the saddle-point method. Conditions for the existence of ordinary and extraordinary wave modes in any given layer are examined. These depend on the relative values of plasma frequency and gyro-frequency. Typical radiation patterns for anisotropic plasma sheaths with linear and parabolic electron-density profiles will be presented for half-wave circumferential and axial slots.

VI. 4-2 RADIATION IN AN ANISOTROPIC SLAB. J. Shmoys, Department of Electrophysics, Polytechnic Institute of Brooklyn, Farmingdale, New York

This paper deals with the radiation from a localized source in a uniaxial grounded slab, when the axis is at an arbitrary angle to the slab surface. For simplicity the value of ε_{33} is taken to be infinite, both in the slab and in the exterior medium. The refractive index surfaces in this case are: a sphere for the

fast mode and a pair of parallel planes for the slow mode. If ε_{11} for the slab is greater than ε_{11} for the exterior medium, then the slab supports a surface wave in the fast mode propagating in the direction of the projection of the medium axis onto the ground plane. For other directions this surface wave degenerates into a leaky wave because of coupling to the slow mode at the ground plane and at the interface between media. As the angle between the axis and the ground plane decreases from 90°, the attenuation first exhibits a maximum and then begins to oscillate rapidly because of interference between the two slow waves. Numerical results showing the dependence of the attenuation coefficient on parameters will be discussed.

A localized source in such a slab radiates a beam in the direction of pure surface wave propagation as a result of this directionally dependent attenuation. The problem is further complicated by the possibility of focusing due to the effect of leakage on the real part of the wavenumber of the leaky wave. The dependence of the beam-width on parameters will be discussed.

VI. 4-3 THE ELECTROMAGNETIC FIELD OF A SLOT-EXCITED MOVING PLASMA SLAB. K. F. Casey, Jr., Department of Electrical Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio

The electromagnetic field radiated by a slot antenna in a ground plane covered with a uniform, isotropic, moving cold plasma layer is determined. The case for which the slot is transverse to the direction of motion of the plasma is considered in some detail. The migration with respect to velocity of the poles and zeros of the integrand in the integral representation for the radiated field is discussed and illustrated with numerical examples. When the layer is stationary, the poles may be of complex spectral, leaky-wave, or proper surface wave type; when the layer is moving sufficiently rapidly, the poles are of leaky-wave or improper surface wave type. Further, a real zero of the integrand can occur for certain ranges of velocity and plasma frequency, causing a null to appear in the radiation pattern.

Several representative radiation patterns are presented and discussed in connection with the pole-zero loci of the integrand. It is found that the motion of the plasma layer can have a profound effect on the radiation pattern, even for relatively small

velocities, if the wave frequency is nearly equal to the plasma frequency.

VI. 4-4 A WAVE TRANSMISSION IN A MAGNETOBIASED IONIZING SHOCK. J. L. Mills, S. T. Hsieh, Y. J. Seto, Electrical Engineering Department, Tulane University, New Orleans, Louisiana

When electromagnetic waves impinge upon a shock front generated by a strong ionizing shock in an electromagnetically driven shock tube, both transmissions and reflections of the incident waves are expected. The addition of externally applied static magnetic field to the shock tube configuration results in an anisotropic post shock moving plasma with numerous possible modes of propagation. When the shock front and the post shock plasma move with sufficiently high speeds, the reflection and the transmission of an incident electromagnetic wave could be expected to differ from that encountered at a stationary magnetobiased plasma boundary.

Based on a rigorous formulation of electromagnetic wave propagation in a bounded moving anisotropic medium, expressions of the transmission factors is obtained. The approach involved the derivation of these factors in the moving frame of reference and then Lorentz transformed the solutions to the laboratory frame of reference.

Computer calculated results of the transmission factors as functions of various shock parameters and shock tube dimensions in some of the feasible modes of post shock propagation are given. Special attention is given to the unattenuated propagating modes. Retrieval of the transmission factors for simple isotropic moving medium is demonstrated by asymtotic approaches.

VI. 4-5 ON RADIATION CHARACTERISTICS OF A PAIR OF CROSSED DIPOLES IN A MULTICOMPONENT MAGNETOPLASMA. T. N. C. Wang, Stanford Research Institute, Menlo Park, California

Considerable work has recently been accomplished on investigating the radiation characteristics from an isolated dipole in a magnetoplasma. However, little effort has been directed to the investigation of radiation properties from any phased array of dipoles in such a medium. The possible gain in radiation efficiency and directivity introduced by a relative phasing between dipole-array elements is important in designing an optimized VLF transmitter in the magnetosphere.

This paper presents some aspects of the input impedance of a circularly phased dipole array--two spatially crossed dipoles with a phase quadrature--embedded in a magnetoplasma. The dipole array is considered to be on the plane perpendicular to the magnetic field, and a triangular-current distribution is used. The total input impedance of this dipole array is given the form: $Z_t = 2Z_{sg} \mp \Delta Z$, where Z_{sg} is the input impedance for a single isolated dipole. The signs " − " and " + " correspond, respectively, to the left (negative) and right (positive) circular phasing between the two dipole elements.

The increment of the input impedance, ΔZ, is caused by the effects of circularly phasing. The formal expression of ΔZ is given by a triple integral involving Bessel functions. Since Z_{sg} is known from several previous works, our efforts have been devoted to the investigation of ΔZ. The $Im\Delta Z$ is, in general, small compared to ImZ_{sg}, and the increment of the radiation resistance ($Re\ \Delta Z$) depends strongly upon the frequency range. For the VLF range, it is found that $|Re(\mp \Delta Z)| < 0.15\ Re(Z_{sg})$ for frequencies $f_{He} > f > f_{LHR}$ (f_{He}, f_{LHR} represent the electron gyrofrequency and the lower-hybrid-resonance frequency, respectively), whereas $|Re(\mp \Delta Z)|/Re\ Z_{sg} \simeq 0.3 - 0.7$ for frequencies $f_{LHR} > f > f_{Hp}$ (f_{Hp} is the proton gyrofrequency).

For the case of signal frequency identical to the cross-over frequency (f_{Co}), $\Delta Z \equiv 0$. To gain radiated power, a right circular phasing should be used for frequencies above f_{Co}, whereas a left circular phasing should be chosen for frequencies below f_{Co}. Some numerical results are presented.

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VI. 4-6 RADIATION FROM SLOT ANTENNAS ON CONES ENCASED IN A LOSSY SHEATH. II. RADIAL SLOT SOURCE AND HOMOGENEOUS SHEATH. Martin Katzin, Electromagnetic Research Corporation, College Park, Maryland

In a previous paper* (to be referred to as I), the case of a ring source and homogeneous sheath, for which only a field of magnetic type is generated, was solved by an extension of the K-L transform technique. In the present paper, the case of a radial slot is treated. Here a field of electric type is created at the boundary because of the azimuthally unsymmetrical excitation. The system of integral equations resulting from the boundary conditions is reduced, by means of the K-L transform, to two integral equations, which may be called the excitation and coupling equations, respectively. The coupling equation expresses the coupling of the electric-type field to that of magnetic type at the sheath boundary, while the other expresses the excitation of the magnetic-type field by the source, including the reaction thereon of the electric-type field. In terms of the quantity

$$\Delta = 1 - (\gamma_2/\gamma_1)^2$$

where γ_1 and γ_2 are the complex propagation constants in the sheath and surrounding medium, respectively, the electric-type amplitude is shown to be $O(\Delta)$. The zero-order term of the magnetic-type amplitude, which is $O(1)$, is just the ring-source solution developed in I. The reaction of the electric excitation on the magnetic excitation then is shown to be $O(\Delta^2)$.

The excitation and coupling equations are solved by the extension of the K-L transform method which was developed in I. The far fields are then determined by the multi-dimensional saddle point method, as in I.

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* RADIATION FROM SLOT ANTENNAS ON CONES ENCASED IN A LOSSY SHEATH I. RING SOURCE AND HOMOGENEOUS SHEATH; Presented at URSI meeting, Washington, D. C., 16 April 1970.

VI. 4-7 COUPLING BETWEEN ELECTROMAGNETIC AND ELASTIC WAVES AT THE INTERFACE OF PIEZOELECTRIC CRYSTALS. C. Yeh, Electrical Sciences and Engineering Department, University of California, Los Angeles, California

Because of its relevance to the design of many useful microwave devices, the problem of the surface wave propagation along the interface of several different piezoelectric solids is of considerable importance. The study of the propagation characteristics of piezoelectric and elastic surface waves on the basal plane of hexagonal piezoelectric crystals, such as CdSe, CdS, ZnO and PZT-4, was first carried out by Tseng and White[1]. Recently, their results were extended by Schmidt and Voltmer[2] to the problem of surface wave propagation along the interface of layered media consisting of a CdS film on a fused quartz substrate. A number of microacoustic circuits, utilizing guided surface waves, which perform circuit functions analogous to those of standard microwave devices, have been proposed by Stern[3].

The purpose of this presentation is to consid_r the problem, the reflection and transmission of an incident plane electromagnetic wave by a piezoelectric crystal half-space of symmetry 6 mm. The crystal is assumed oriented with its c axis normal to the interface[4]. Results on the variation of the reflection and transmission coefficients, the coupling between the electromagnetic and elastic wave energies, and the angles of reflection and transmission, as a function of the incident angle will be discussed.

1. C. C. Tseng and R. M. White, J. Appl. Phys. 38, 4274 (1967).
2. R. V. Schmidt and F. W. Voltmer, IEEE Trans. on Microwave Theory and Techniques, MTT-17, 920 (1969).
3. E. Stern, IEEE Trans. on Microwave Theory and Techniques, MTT-17, 835 (1969).
4. J. F. Nye, Physical Properties of Crystals, Oxford University Press, New York (1967).

VI. 4-8 PROPAGATION CHARACTERISTICS OF MULTI-MODE DIELECTRIC WAVEGUIDES AT OPTICAL FREQUENCIES. Ronald Roberts, Department of Mathematics, University of Dundee, Dundee, Scotland

A theoretical investigation has been made of the characteristics of the modes that may propagate along a circularly cylindrical waveguide consisting of three coaxial lossy dielectric media. The inner core may be many wavelengths in diameter and is surrounded by an annular cladding of lower refractive index. The outer dielectric is arbitrary and, in particular, may be highly absorbing.

The general characteristic equation for the propagation coefficients of the modes has been derived in explicit form. This has been solved numerically to give very accurate values for the phase coefficients of all modes.

Exact expressions have been obtained for the power flow, power loss and energy storage in each medium. Energy transport considerations have been used to obtain expressions for the group velocities of the modes. A perturbation method has been used to obtain closed form expressions for the separate contributions of each medium to the attenuation coefficients. Numerical values have been obtained for the group velocities and attenuation coefficients of all modes.

Emphasis is placed on the presentation and discussion of the numerical results, rather than on the mathematical analysis. These results should be useful in the design of multi-mode dielectric waveguides for optical communications.

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0900 Thursday, September 17 — 031 Hitchcock Hall

COMMUNICATIONS IN DENSE MEDIA

Bernard D. Steinberg, Chairman

VI. 5-1 TYPES OF WAVE PROPAGATION IN FOREST ENVIRONMENT*.

T. Tamir, Department of Electrophysics, Polytechnic Institute of Brooklyn, Brooklyn, New York

The difficulties encountered in radio communication along a path that lies entirely or partly within a forest have been the subject of considerable recent studies. The aim of the present paper is to assess the effect of vegetation on wave propagation over a frequency range that spans the entire VLF to UHF spectrum, and to suggest the specific wave mechanism that accounts for the principal field contribution in a large variety of typical cases. In particular, it will be shown that frequency is only one of several other physical parameters that determine the type of wave which optimizes the transfer of energy between two points in the presence of vegetation. These parameters include the foliage density, the distance between the receiver and transmitter, the antenna height, the electric properties of the ground and the extent of vegetation coverage along the communication path, as well as other possible factors. Depending on the particular combination of these various parameters, the strong field contributions may be produced by a ground wave, a sky wave, a lateral wave or possibly a wave that progresses essentially along a "line-of-sight" path. In certain situations, only one of these waves is responsible for the dominant electromagnetic field; as an example, when both the receiving and the transmitting points are located within the forest, it was shown that a lateral wave mechanism is usually dominant at frequencies between 2 and 200 MHz. However, when one of the two points is outside the forest, the propagation mechanism may contain either a single wave variety (e.g., a refracted "line-of-sight" wave), or a combination of several wave types (e.g., a lateral wave and a ground wave). Several representative situations will be discussed and the considerations for determining the most likely wave propagation mechanism will be presented for each case.

*Portions of this work were supported by the Communication/ADP Laboratory, U.S. Army Electronics Command, Fort Monmouth, N. J.

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VI. 5-2 COMMUNICATIONS VIA DIFFICULT-DENSE MEDIA.
Kurt Ikrath, U.S. Army Electronics Command, Fort Monmouth, New Jersey

The basic principles and criteria that are needed for an understanding of the phenomena that govern the insertion, propagation and extraction of electromagnetic and seismic signals in heterogeneous media of limited linear behavior will be explained and discussed by referring to photographs of photoelestic stress wave propagation in diverse media.

The first area of discussion will cover the problems associated with electromagnetic communications in a jungle environment plus a review of the effort being expended to overcome these problems by the use of the Hybrid Electeromagnetic Antenna Couplers (HEMAC). The results of field experimentation, complete with the radiation patterns of the HEMAC operating in a jungle environment, will be presented.

The second area of discussion deals with the problems of seismic communications in various terrains. Methods for communication between surface to surface locations, surface to underground locations, surface to water locations and ice to water locations will be discussed. Experimental results will be given plus an explanation of the effects of the environment on propagation.

The third area for discussion will include the problem of Transmission of Radio Correlated Low Audio and Sub Audio Frequency Electrical Conduction Current Signals through Seawater. Here again, methods, problems and results of experimentation will be given, discussed and explained.

A summary of the programs that were carried out plus conclusions arrived at and possible new areas of investigation for the future, such as the use of railroad track for communications at LF will be given.

VI. 5-3 REVIEW OF PROBLEMS ASSOCIATED WITH COMMUNICATIONS THROUGH PLASMAS.
Robert J. Papa, Microwave Physics Laboratory, Air Force Cambridge Research Laboratories, L. G. Hanscom Field, Bedford, Massachusetts

The problems involving communications through plasmas may be classified into two categories: case I - Transmission through a plasma in which transmitter and receiver are not in contact with the plasma and case II - Transmission through a plasma in which the transmitter is imbedded in the plasma. In case I, which includes ground-to-satellite and ground-to-ground communication links, the plasma can cause electromagnetic wave attenuation, phase shift and wave refraction. Four basic theoretical models of a plasma exist which can be used to predict the dielectric properties of the medium, where each model has its advantages and limitations. Wave refraction effects caused by inhomogeneities can be analyzed using ray tracing techniques or by numerical integration techniques using stratified models.

In case II, the contact between plasma and antenna surface can alter the radiation pattern of the antenna due to the following phenomena: (a) the formation of an inhomogeneous plasma sheath next to the antenna surface (b) the modification of the current distribution on the antenna. These direct plasma contact phenomena have been analyzed for a number of geometrical configurations: the electric dipole, the magnetic dipole, the slot on a ground plane, the slot on a sphere and the slot on a cylinder. The near fields of an antenna may become intense enough to cause plasma heating which will alter the electromagnetic radiation characteristics. Future efforts should be devoted to such nonlinear effects and also to the analysis of the interaction of the plasma with the antenna surface using more realistic boundary conditions than hitherto.

VI. 5-4 A STATISTICAL MODEL FOR URBAN MULTI-PATH PROPAGATION. K. H. Powers, RCA Laboratories, Princeton, New Jersey

Extensive propagation measurements at 1 GHz and 10 GHz over non-line-of-sight paths are now being made in New York City and a few smaller urban areas. The measurements involve a low (30') transmitting antenna height and a mobile receiving antenna. From these data and others, a statistical model is developed for expected field strength versus distance and coherence distance as functions of frequency, transmitting antenna height, and terrain irregularity. Extrapolation into millimeter waves is attempted. This model should be useful for estimating power requirements for short range communication both with and without diversity reception.

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VI. 5-5 MOBILE RADIO COMMUNICATIONS IN URBAN ENVIRONMENTS. William V. Braun, Motorola, Inc., Schaumburg, Illinois

This paper presents a charactrrization of the mobile radio environment in major urban areas. The principal emphasis is on those factors in the environment which degrade the performance of radio systems in comparison to the predictions of classical propagation theory. Consideration is then given to the selection of modulation techniques which minimize this degradation.

Four categories of "urban factors" are discussed which modify classical propagation predictions statistically in terms of lowering the reliability of communications. These "urban factors" are:

1. man-made noise
2. shadowing or gross terrain effects
3. multipath
4. interference

Empirical results in statistical form are given to describe the first three factors which can be thought of as permanent features of the terrain in a given locality. The fourth factor, interference, is however a consequence of the interaction of a multiplicity of radio users in a dense radio environment. The concept of an interference limited channel is presented. Empirical results, a queuing theory model and computer simulation studies are presented to relate the interference factor to the other "urban factors."

The relative importance of each of the "urban factors" is shown to vary widely in specific situations. This is attributed to the wide variation in mobile radio frequencies which are scattered over roughly five octaves of frequency in the VHF and UHF bands.

Finally, modulation techniques are considered for voice and data communications. Results are presented on the relative merits of SSB and narrowband FM for voice communication and signal design and the use of redundant coding in data transmission.

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0900 Thursday, September 17 — 035 Hitchcock Hall

ARRAYS

Louis Stark, Chairman

√ VI. 6-1 RELATION OF THE SUPERGAIN FACTOR AND THE SENSITIVITY TO ERRORS FOR SOME CRITICAL ANTENNA ARRAY DESIGNS.

G. A. Deschamps, H. S. Cabayan, University of Illinois, Department of Electrical Engineering, Urbana, Illinois

Some critical antenna designs lead to high reactive fields near the radiating structure and therefore to high losses and to a high sensitivity of the pattern to errors in the aperture function. This is the case when one tries to obtain a gain incompatible with the size of the antenna or more generally when one tries to approach a desired pattern that is strictly unattainable.

The design then must be a compromise between the "distance" ε_α from the actual to the desired pattern, the norm $||f||$ of the aperture function for which a unit power is radiated, and the sensitivity represented by the error ε_ν in the pattern due to a random relative error ν of the aperture function.

Tihonov's regularization algorithm [1,2] can be used to produce a family of designs which depend on a parameter α. It is found that as α approaches 0 the error ε_α decreases but the norm $||f||$ and the sensitivity to error ε_ν both increase.

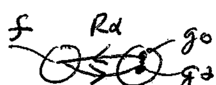
The square norm $||f||^2$, for unit power radiated, is also the supergain ratio Q introduced by Taylor [3]. It is directly related to the ohmic losses in the antenna. The sensitivity to error is equally important in choosing the proper value of α. Although it varies in the same direction as Q, it is not directly proportional to it. In this paper we establish a general relation between Q and ε_ν that is valid for a linear array of antennas having an arbitrary element pattern. The array may be discrete or continuous. It is observed that the introduction of random errors in the aperture function produces a decrease of the factor Q, that is an increase of the power radiated for a given norm of the aperture function. If $Q \cos \Theta$ represents the altered factor Q, it can be shown that the relative error.

$$\varepsilon_\nu = 2 \sin \frac{\Theta}{2} \qquad (1)$$

It is also found that the angle Θ is related to the mean square

$||Tf - g_0||^2 + \alpha||f||^2$ minimum

$R_\alpha = (TT^* + \alpha)^{-1} T^*$



level of error ν by

$$\tan \Theta = \nu \sqrt{R Q} \quad (2)$$

where R is the radiation resistance of one element of the array taken alone.

These results have been applied to the study of an array of coaxial dipoles designed to produce an almost isotropic radiation pattern. The formulas for $\cos \Theta$ and ε_ν have been verified by actual computations of several designs and for each design by applying some 25 independent random variations of level ν to the aperture function. The agreement is very satisfactory and the formulas (1) and (2) provide a useful guide in choosing the amount of regularization.*

VI. 6-2 RADIATION PATTERN, IMPEDANCE AND GAIN OF AN ELEMENT IN A CONFORMAL ARRAY OF APERTURES ON A LARGE CIRCULAR CYLINDER. Giorgio V. Borgiotti and Quirino Balzano, Raytheon Company, Bedford, Massachusetts

The most successful methods of analysis of planar arrays are based on the possibility of modeling a large phased array as an infinite double periodic structure. In this paper a conceptually similar method is exploited for the analysis of an infinite array of apertures forming a rectangular or triangular grid on a cylindrical surface. If edge effects are neglected, the analysis is applicable to conformal arrays occupying a finite portion of cylindrical surface. Because of the structure symmetries, every possible excitation of the array is the superposition, with suitable weights, of a set of fundamental excitations having uniform amplitude and linear phase tapers in the azimuthal direction and in the direction of the cylindrical axis. Thus the analysis of the array is reduced to the solution of the boundary valued problems for these fundamental set of excitations. This is done by expanding the field in normal

*
1. Tihonov, A.N., Soviet Math., Dokl. 5, 835, (1964).
2. Cabayan, H.S., G.A. Deschamps and P.E. Mayes, URSI 1969, Fall Meeting, pp. 38-39.
3. Taylor, T.T., IRE Trans, on Antennas and Propagation, Vol. AP-3, pp. 16-28, January 1955.

Acknowledgement The work in this paper was supported by NSF Grant GK-2120 and in part by a subcontract of M.I.T. Lincoln Laboratory, Lexington, Mass. (operated with support from the U.S. Air Force).

modes in the region exterior to the cylinder and in the waveguides feeding the apertures, followed by a field matching at the cylinder surface. Two sets of equations are established (pertaining to the continuity of the electric and magnetic tangential fields), and these may be solved approximately by applying Galerkin's method. As a numerical example, the realized gain pattern of an element in a large array of circular apertures is evaluated in both cases of linear and circular nominal polarizations.

VI. 6-3 ANTENNA ARRAYS OVER LOSSY GROUND. G. J. Burke, E. K. Miller, A. J. Poggio, E. S. Selden, MB Associates, San Ramon, California

Perhaps the most widely studied problem involving the interaction of an antenna with its environment is that of a vertical electric dipole located over a homogeneous half-space of arbitrary electrical parameters. The foundation for a formal solution of this problem was laid in 1909 by Sommerfeld. Owing to the difficulty in obtaining accurate numerical values for the Sommerfeld integral which accounts for the half-space, attention to date has been primarily limited to obtaining approximate solutions for elementary sources. This restriction can be overcome by using an adaptive numerical quadrature technique together with contour deformation into the complex plane to efficiently, but accurately, evaluate the Sommerfeld integral.

As a result, the current distribution on a wire antenna of arbitrary length over a half-space can be solved as a boundary value problem from the thin-wire version of the electric field integral equation, modified by inclusion of the Sommerfeld integral. A simple extension of the formulation to two or more vertical antennas makes practicable the analysis of general antenna configurations such as a log-periodic array. Numerical results will be shown for both the single antenna, for comparison with previous work, as well as for more complex antenna arrays, to demonstrate the method's capability and the sensitivity of the important antenna performance factors to the ground parameters. The usefulness of various approximations to account for the finite ground conductivity will also be discussed.

VI. 6-4 STUDY OF A PERIODICALLY-MODULATED SLOW-WAVE SCANNING ANTENNA. Boaz Gelernter, U.S. Army Electronics Command, Fort Monmouth, New Jersey, Alexander Hessel, Arthur A. Oliner, Polytechnic Institute of Brooklyn Graduate Center, Farmingdale, N. Y.

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This paper is concerned with the properties of a periodically-modulated, slow-wave structure having a single leaky space-harmonic component. It has been predicted that flat, relatively compact structures of this type would be capable of wide-angle beam scanning with relatively small changes in frequency in a manner similar to much heavier and more complex serpentine arrays.

The structure investigated, both theoretically and experimentally, utilized a feed waveguide with inner dimensions of 2.84" by .25", completely filled with a high dielectric constant material having an effective ε of 13.1. The top wall of the guide was replaced by a series of blocks having gaps 2.84" long and of variable width b, with the long gap-dimension perpendicular to the axial direction of the feed guide and spaced periodically along this direction with a period of 1". The region containing the slotted top surface of the blocks is enclosed by two short parallel planes, which were flared out at the top in the H-plane. Energy from the dielectrically-loaded feedguide is thus coupled out via a series of E-plane Tees and short air-filled waveguides and radiated from the open ends of these guides which are arrayed in the E-plane between parallel metallic planes.

In the analysis of this antenna structure, a dual approach was used to establish the fundamental propagation wavenumber κ_c of the structure as a function of b. In the longitudinal method a unitcell approach was used to derive an expression for the aperture admittance Y_r (κ_c) of a slot in the presence of an infinite number of like neighboring slots. By the use of a network representation for the E-plane Tee and of Floquet's Theorem, it was possible to derive a dispersion relation which was then solved for κ_c(b). Results obtained by the above method are compared to those obtained by means of a transverse resonance analysis. Values of attenuation and phase constant, as a function of b and frequency, for arrays of 37 identical slots were obtained by means of bench measurements and far-field pattern measurements. Results obtained by the two theoretical approaches were in good agreement with each other, as were the values measured by the two experimental methods. The agreement between theory and experiment for the phase constant β was excellent, and the antenna scanned as predicted. The agreement for the attenuation constant α is reasonably good, but is limited by losses and by the presence of small amounts of spurious higher modes.

Implications for practical extremely-wide-angle scanning antennas will be presented.

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VI. 6-5 RESONANCES IN CIRCULAR ARRAYS WITH DIELECTRIC SHEET COVERS. J. C. Sureau, Grumman Aerospace Corp., Bethpage, L. I., New York, A. Hessel, Polytechnic Institute of Brooklyn, Graduate Center, Farmingdale, New York

The effect of a dielectric sheet cover on the E-plane realized element gain pattern of a circular array of axial thin slits is considered. In similar planar arrays, such patterns are characterized by nulls which appear even for spacings less than $\lambda/2$. This phenomenon has previously been linked with the influence of a leaky wave on the near field. It is shown in this paper that, in circular arrays, similar dips occur accompanied by pattern distortions.

The analytical procedure is similar to that used in uncovered arrays. The associated admittance crater exhibits a resonance in the susceptance, as in the equivalent planar array. It can be shown that the asymptotic evaluation of the results lead to a decomposition of the overall pattern into a space wave and creepingwave contributions. The space wave is almost identical to the planar result and exhibits a pronounced dip predictable from the admittance crater. The significant creeping waves are residue contributions from the dielectric-induced leaky wave poles, which, in contrast to planar case, contribute directly to the far field.

Numerical results for the element pattern (via harmonic series) and for the space wave show that, for a given radius, the pattern dips caused by dielectric resonances are much more pronounced than the grating lobe dips in corresponding uncovered circular arrays, and that the distortions caused by the creeping waves increase with spacing.

VI. 6-6 PHASED ARRAYS WITH PROTRUDING-DIELECTRIC LOADED PARALLEL PLATE WAVEGUIDE ELEMENTS. L. R. Lewis, Raytheon Co., Bedford, Mass., A. Hessel, Department of Electrophysics, Polytechnic Institute of Brooklyn, Graduate Center, Farmingdale, New York

The E-plane scan of phased arrays of open ended dielectric loaded parallel plate guides, where the dielectric extends beyond a conducting ground plane is considered. Protruded dielectric loading provides a simple and inexpensive matching of elements to free space.

A formulation for the active input reflection coefficient has been developed in terms of the scattering matrices for each of the junctions - the waveguides aperture discontinuity and the dielectric-air interface. The individual scattering matrices are obtained via Galerkin's method. Application of this method requires the knowledge of the modes propagating normally to the array face along the array of dielectric slabs formed by the protrusion. A complete set of closed form orthonormal mode functions and corresponding wavenumbers has been determined.

The individual scattering matrices possess appropriate symmetry under the transformation $\Theta \rightarrow -\Theta$. Power conservation has been demonstrated formally and numerically. Numerical solutions have been obtained for the active input reflection coefficient as a function of scan angle and physical parameters. Guided wave resonances appear and manifest themselves in the element pattern. Preliminary experimental results on a small waveguide array indicate agreement with the theory.

VI. 6-7 AN ADAPTIVE-PROGRAMMABLE PHASED ARRAY. Andrew E. Zeger, Edwin D. Banta, General Atronics Corporation, Subsidiary Magnavox Company, Philadelphia, Pa.

To create a large aperture airborne antenna that is capable of being rapidly scanned and is aerodynamically viable requires a conformal phased array. Antenna tolerance theory predicts that the random antenna (airframe) deformations in flight will reduce gain and increase sidelobe levels.

A design of an airborne phased array radar which initially employs self-phasing to correct for aperture deformation has been presented.* Synthetic aperture processing provides the far field source for phase alignment. After alignment the array is phase steered by a scanning program like a conventional (rigid) array.

Here we evaluate the improvement obtained by the optimum and suboptimum use of self-phasing information to correct for element

*"A Large Self-Phasing Airborne Radar Array," B. D. Steinberg, D. N. Thomson, H. Urkowitz, A. E. Zeger, and E. D.Banta, presented at the Fall USNC/URSI Meeting, Austin, Texas, 8 December 1969.

displacement during programmed scanning. For element displacements on the order of $\lambda/4$, the beam can be steered 30° away from the self-phasing direction without serious loss of gain. The antenna pattern deteriorates as the scan angle increases at a rate proportional to the magnitude of the element location errors.

The information generated during self-phasing is also used to estimate the aperture deformation. An adaptive algorithm predicts the scan angle at which the pattern will deteriorate beyond a tolerable level. Statistical analysis yields the average array power pattern. Patterns are presented for several scan angles.

Portions of this work were supported by the U.S. Air Force under Contracts AF33(615)-2592 and AF33(615)-5443.

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ANTENNAS

C-T. Tai, Chairman

VI. 7-1 PARASITIC ARRAY OF TWO LOADED SHORT ANTENNAS WITH ENHANCED RADIATION OR HIGH DIRECTIVITY: THEORY AND EXPERIMENT. C. J. Lin, Electrical Engineering Department, University of Detroit, Detroit, Michigan; D. P. Nyquist, K. M. Chen, Department of Electrical Engineering and Systems Science, Michigan State University, East Lansing, Michigan

A short cylindrical antenna is a radiating element characterized by: (1) low radiated power resulting from an input impedance with small resistive and large reactive components and (2) a broad radiation pattern with small directivity. Previous research by the authors[1] has demonstrated the feasibility of improving these characteristics by a double impedance loading technique. The objective of the present research is to extend this study to a parasitic array of two coupled, loaded short antennas. It is demonstrated that the current distributions in the array elements can be appropriately modified by an optimum impedance loading to achieve significant improvements in radiated power and directivity.

Each element of the parallel array of two closely-spaced, short cylindrical antennas (half-length $\leq 0.1\ \lambda_o$) is doubly loaded by lumped impedances. Hallen-type integral equations for the element currents are solved by Mei's numerical approach [2] and according to King's two-term theory [3], and the results of the two methods are compared. The current distributions on both array elements and the input impedance to the driven element are determined in terms of the array dimensions and the positions and impedances of the loadings. Optimum loadings to achieve enhanced radiation or improved directivity are determined from these results.

It is demonstrated that element currents having nearly constant amplitude and phase distributions can be implemented by an optimum reactance loading. The resistive component of the array input impedance is greatly increased while its reactive component is tuned to zero, resulting in significantly enhanced radiated power.

The research reported in this paper was supported by the Air Force Cambridge Research Laboratories under contract AF 19(628)-5732.

Increased resistance by a factor of 10 to 20 and nearly reduced reactance to zero. The load gives near uniform current dist.

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An optimum reactance loading can also be utilized to implement a phase reversal of the current distributions in the array elements. A sharper radiation pattern results, and a short array of significantly improved directivity is consequently achieved.

Results of the theoretical study are confirmed by experimental investigations on the currents and impedances of short arrays appropriately loaded for enhanced radiation or high directivity. This research should prove useful in the design of practical short arrays with improved circuit or radiation properties.

1. Lin, C. J., D. P. Nyquist and K. M. Chen, "Short Cylindrical Antennas with Enhanced Radiation or High Directivity", IEEE Trans. on Antennas and Propagation, Vol. AP-18, No. 4, July 1970.
2. Mei, K. K., "On the Integral Equations of Thin-Wire Antennas", IEEE Trans. on Antennas and Propagation, Vol. AP-13, No. 3, May 1965, pp. 374-378.
3. King, R. W. P. and T. T. Wu, "Currents, Charges, and Near Fields of Cylindrical Antennas", Radio Science J. Res. NBS, Vol. 69-D, No. 3, March 1965, pp. 429-446.

✓ VI. 7-2 THEORY OF VOR ANTENNA RADIATION PATTERN.*

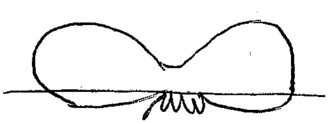
Dipak L. Sengupta, The Radiation Laboratory, Department of Electrical Engineering, The University of Michigan, Ann Arbor, Michigan

110-120 MHz

The existing VOR antenna system consists of four Alford loops placed suitably above a circular conducting ground plane or counterpoise. At any instant of time only two of the loops are excited with equal amplitude but opposite phase. The pattern of the antenna in the horizontal plane is a figure-of-eight. The elevation pattern has a maximum in the direction 50° -60° above the horizon and has a minimum (ideally a null) in the axial direction.

Although this antenna has been in use for VHF omnirange for many years and its patterns are well documented experimentally, there is no satisfactory theory. In the present paper a theory for the radiation patterns produced by such antennas has been developed by utilizing the concepts of geometrical theory of diffraction.

* The research reported in this paper was sponsored by the Federal Aviation Administration under Contract FAA 69 WA-2085.



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The theory is then compared with the measured patterns for different sizes of the ground plane. The agreement between the two has been found to be very good. The essential contribution of the paper is the development of a theory for the radiation patterns produced by the existing VOR antennas.

VI. 7-3 BROADBAND COMA-CORRECTED REFLECTOR ANTENNAS.*

A. R. Panicali, Y. T. Lo, G. A. Deschamps,
Antenna Laboratory, University of Illinois

In view of the high cost of large steerable reflector antennas and the complexity of phased arrays it is desirable to seek other means for beam scanning such as feed displacement or electronic control of reflector properties. Scanning by feed displacement cannot be achieved with a conventional parabolic reflector because of coma aberration. On the other hand, a spherical reflector requires a large complex movable feed system to compensate for the inherent spherical aberration. Coma-corrected zoned reflectors have been investigated and found to have good scanning property but suffers from large chromatic aberration.

In this paper a new aplanatic reflector, corrected for all these aberrations, will be discussed. In this system the time-delay, rather than the phase, associated with each ray reflected from a spherical (in the 3-dimensional case) or a circular-cylindrical (in the 2-dimensional case) reflector is so adjusted that the Abbe's sine condition is satisfied. In the case of cylindrical reflector this can be achieved, for example, by a corrugated structure of parallel plates since it is non-dispersive insofar as the TEM wave is concerned. In the case of 3-dimensional reflector, this may be achieved by using non-dispersive transmission line or approximately by ordinary waveguide structures. A detailed theoretical and experimental study of a 2-dimensional model has been conducted. The results show that the beam can be scanned to as far as $\pm$ 30° over a frequency band of at least 30% with practically no deterioration. Possible extensions to electronic scanning with a fixed feed and active reflectors will be discussed.

* This work is supported by a grant from NSF GK-2120.

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VI. 7-4 ANTENNAS ON SPHEROIDS WITH A VARIABLE SURFACE IMPEDANCE.

N. G. Alexopoulos, Electrical Sciences and Engineering Department, University of California, Los Angeles; P. L. E. Uslenghi, Radiation Laboratory, Department of Electrical Engineering, The University of Michigan, Ann Arbor, Michigan

The electromagnetic radiation from antennas mounted on prolate and oblate spheroids with a variable surface impedance is considered. The antennas are electric or magnetic dipoles located on the axis of symmetry and axially oriented, or annular slots with an azimuthally uniform field distribution. It is shown that for certain functional forms of the surface impedance, the boundary-value problem is amenable to exact solution by separation of variables. Expressions for the field components at any point in space are given, and particular attention is devoted to surface fields and radiation patterns.

The practical realizability of the surface impedance variations is discussed in terms of an absorbing coating layer of variable thickness for inductive impedances, and of corrugations of different shapes and dimensions for capacitive impedances.

When two antennas are symmetrically located with respect to the center of the spheroid and are excited either in phase or in opposition, the radiated field is expressible in terms of odd or even spheroidal functions only. For prolate spheroids and resonant frequencies, only trigonometric functions are involved [1,2], and the radiation pattern is given by a simple expression.

The coupling between two annular slots is analyzed and formulas for self and mutual admittances are given. For a perfectly conducting spheroid, previously known results [3] are obtained as a particular case.

This research was supported by the National Science Foundation under Grant GK-5433.

[1] R. M. Ryder, J. Appl. Phys. 13, 327 (1942).
[2] C. Flammer, Spheroidal Wave Functions, Stanford University Press (1957).
[3] D. A. Duplenkov and A. N. Kovalenko, Soviet Phys.-Techn. Phys. 10, 1109 (1966).

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VI. 7-5 CHARACTERISTICS OF A HORIZONTAL, INFINITELY-LONG ANTENNA OVER A CONDUCTING HALF-SPACE.

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

The radiation characteristics of a long, thin-wire antenna, located in the air above a homogeneous, conducting half-space is of interest in connection with the performance of radiating systems in the presence of a lossy earth. Recently, there is also a need to use the antenna as a diagnostic probe for sensing the electrical parameters of an unknown environment. For the case of an infinitely-long antenna, the existence of an attenuated, "ground-return", transmission current is usually assumed.* This assumption appears to be valid only if the antenna is placed close to a highly conducting half-space. In general, the problem can be investigated from the knowledge of its current distribution, using an integral equation formulation for an antenna of arbitrary length. Excitation can be provided by a voltage source across a small gap on the antenna. It follows that an infinite wire antenna can be characterized by two separate current distributions, one corresponding to a lossy, transmission line and the other, a radiating antenna in the air. At a fixed height, input conductance associated with the "transmission" current (G_t) is more pronounced for a higher conductive half-space, than that of the "radiation" current (G_r). As the antenna height increases, G_t decreases monotonically, and G_r increases, while at the same time modulated by a decreasing oscillation. Numerical examples are then given corresponding to various earth materials.

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* H. Kikuchi, Electrotech. J. Japan, Vol. 2, No. 314, 1956.

Sky King Family

VI. 7-6 EXPERIMENTAL STUDY OF COUPLED THICK ANTENNAS.

Bob M. Duff, Gordon McKay Laboratory, Harvard University, Cambridge, Massachusetts, now with the Department of Electrical Engineering, Northeastern University, Boston, Massachusetts

An experimental study was made of two identical parallel dipole antennas of electrically large radius. In the experimental system the antennas were formed by extensions of the inner conductors of coaxial lines whose outer conductors terminated on an image plane. The experiment covered antennas of electrical radii ka = 0.318, 0.639, and 0.877, with heights above the image plane from $\lambda/4$ to $3\lambda/4$ and spacings between antennas of $\lambda/2$ to

$3\lambda/2$. The apparent input admittances were measured for both symmetric and antisymmetric drive conditions of the two antennas. From these measurements self and mutual admittances were computed and are presented as functions of both antenna height and antenna spacing. A comparison is made between the admittance behavior of thick and thin antennas. The current on the surface of the antennas was measured as a function of both axial and transverse position. It is shown that the coupling between thick antennas produces a transverse variation of the axial component of current and introduces a transverse component of current near the driving point and upper end of the antennas. Theoretical predictions of the current distributions are compared with the observed values and good agreement is shown for the larger antenna spacings.

VI. 7-7 CURRENT AND IMPEDANCE OF A CYLINDRICAL ANTENNA IN A HOT PLASMA--THEORY AND EXPERIMENT. Kun-Mu Chen, Garth Maxam, Department of Electrical Engineering and Systems Science, Michigan State University, East Lansing, Michigan

A simple integral equation for the induced current of a cylindrical antenna in a hot plasma is derived. Zeroth-order solutions for the antenna current and the input impedance are obtained. Effects due to the electroacoustic wave on the antenna circuit properties are examined. An experiment has been conducted in which a monopole of variable length was inserted in a large volume of confined mercury arc discharge. The antenna current distribution was directly probed and the input impedance was measured. Theoretical and experimental results are compared.

A new integral equation for the current, $I_z(z)$, on a cylindrical antenna with a radius a, a length 2h and driven by a voltage V_o at the center is derived as

$$\int_{-h}^{h} I_z(z')[K(z,z') - \sec k_e h \cos k_e z \, K(h,z')]dz'$$

$$= \frac{jV_o}{2\sqrt{\mu_o/\xi}} \sec k_e h \sin k_e (h - |z|) \qquad (1)$$

where

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$$K(z,z') = G_e(z,z') - \frac{\omega_p^2}{k_e(\omega^2 - j\omega\upsilon)} \int_0^z \frac{\partial^2 G_p(z'',z')}{\partial z'^2} \sin k_e(z-z'')dz'' \tag{2}$$

$$G_{e,p}(z,z') = \frac{\exp\left[-jk_{e,p}\sqrt{a^2 + (z-z')^2}\right]}{\sqrt{a^2 + (z-z')^2}},$$

$k_{e,p}$ = propagation constant of $\left\{\begin{matrix}\text{electromagnetic}\\ \text{electroacoustic}\end{matrix}\right\}$ wave

Based on Eqs. (1), the zeroth-order antenna current can be derived to be

$$I_z(z) = \frac{jV_o}{2\sqrt{\mu_o/\xi}} \frac{\tan k_e h}{c} \sin k_e(h - |z|) \tag{3}$$

where

$$C = \int_{-h}^{h} \sin k_e(h - |z'|)[K(0,z') - \sec k_e h\, K(h,z')]dz' \tag{4}$$

The zeroth-order input impedance can be obtained as

$$Z_o = -j2\sqrt{\mu_o/\xi} \cot k_e h\, C/\sin k_e h \tag{5}$$

The antenna current and the input impedance involve a double integral and were numerically calculated by a CDC 6500 computer.

Experimentally the antenna current distributions and antenna input impedances for cylindrical monopoles of various lengths were measured under various plasma densities. Some of these experimental results are compared with the theoretical results calculated based on Equations (3) to (5).

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The effect of the electroacoustic wave on the antenna circuit properties was examined.

The present theory is relatively simple and may prove useful in practical applications.

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