WA Davis

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

UNITED STATES NATIONAL COMMITTEE
International Union of Radio Science

National Radio Science Meeting

May 24-28, 1982

Sponsored by USNC/URSI
held jointly with
International Symposium of
Antennas and Propagation Society
Institute of Electrical and Electronics Engineers
and
Nuclear Electromagnetic Pulse Meeting
University of New Mexico
Albuquerque, New Mexico
U.S.A.

TECHNICAL PROGRAM SUMMARY
MAY 1982 JOINT URSI (B, E, F)/APS/NEM MEETING
UNIVERSITY OF NEW MEXICO, ALBUQUERQUE

LOCATION	MONDAY, MAY 24		TUESDAY, MAY 25		WEDNESDAY, MAY 26		THURSDAY, MAY 27		FRIDAY, MAY 28
	8:30 - 12:00	1:30 - 5:00	8:30 - 12:00	1:30 - 5:00	8:30 - 12:00	1:30 - 5:00	8:30 - 12:00	1:30 - 5:00	8:30 - 12:00
North Ballroom, Student Union Bldg.	AP-1 Scattering	AP-4 Components	AP-9 Antenna Measurements	AP-12 Wave Propagation		AP-15 Antennas in Systems AP-16 Coherence and Interference	AP-19 Numerical Methods for Scattering	AP-22 Analytical and Numerical Methods for Antennas	AP-25 Inverse Scattering & EM AP-26 Remote Sensing
Central Ballroom, Student Union Bldg.	AP-2 Tolerances & Distortions in Antenna Systems	AP-5 Lens Antennas	AP-10 Shaped Reflector Antennas	AP-13 Multiple-Beam Satellite Antennas		AP-17 Phased Arrays	AP-20 Arrays and Array Elements	AP-23 Reflector Antenna Computational Techniques	AP-27 Low Sidelobe and Adaptive Arrays
South Ballroom, Student Union Bldg.	AP-3 Microstrip Antennas I	AP-6 Microstrip Antennas II	AP-11 Microstrip Antennas III	AP-14 Helical and Circular Antennas	PLENARY SESSION	AP-18 Dichroic Surfaces and Reflector Antennas	AP-21 Small and Compact Antennas	AP-24 Microwave and Millimeter Wave Antennas	AP-28 Multiple-Beam Antennas
Room 103, Education Center	URSI-B-1 Media Interface Effects URSI-B-2 Aperture Theory	URSI-B-4 AP-7 Deschamps Session	URSI-B-5 Electromagnetic Theory	URSI-B-7 High Frequency Techniques (GTD)		URSI-B-9 Scattering	URSI-B-12 Inverse Scattering I	URSI-B-14 Inverse Scattering II	URSI-B-15 Antenna Theory II (Microstrip)
Room 101, Education Center	URSI-B-3 Guided Waves		URSI-B-6 Propagation Theory	URSI-B-8 Numerical Methods	STUDENT UNION BALLROOM	URSI-B-10 Antenna Theory I	URSI-B-13 Transients and SEM		
Room 104, Education Center	NEM-1 Cable and Enclosure Shielding	NEM-4 Multi-Conductor Cable Responses	NEM-6 Numerical Techniques	NEM-9 Source Region Analysis NEM-10 System Level Testing		URSI-B-11 URSI-E-5 NEM-12 Scien. Basis for Noise & Interference Control	NEM-14 Interaction Analysis	NEM-16 System Interaction	NEM-18 Nonlinear Breakdown Phenomena
Kiva Auditorium	NEM-2 EMP Hardness Assessment	NEM-5 Failure Thresholds	NEM-7 Source-Region Interaction	NEM-11 Instrumentation for EMP Measurements		NEM-13 EMP Simulation Technology I	NEM-15 EMP Simulation Technology II	NEM-17 System Hardening Technology	NEM-19 Scale Model Measurements & Extrapolation NEM-20 Hardness Assurance Monitoring Systems
Room 204, Education Center	URSI-E-1 NEM-3 Lightning I	AP-8 Tropospheric Propagation URSI-E-2 Shielding	URSI-E-3 NEM-8 Lightning II	URSI-E-4 Noise Measurements and Interference		URSI-F-1 Remote Sensing	URSI-F-2 Propagation I	URSI-F-3 Propagation II	URSI-F-4 Propagation III

United States National Committee

INTERNATIONAL UNION OF RADIO SCIENCE

PROGRAM AND ABSTRACTS

1982 Spring Meeting

May 24-28

Held Jointly with

ANTENNAS AND PROPAGATION SOCIETY

INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS
AND
PERMANENT NEM COMMITTEE

Albuquerque, New Mexico

NOTE:

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

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

at $2 for meetings prior to 1970, $3 for 1971-75 meetings, and $5 for 1976-82 meetings.

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

WELCOME
TO
ALBUQUERQUE

On behalf of the IEEE Antennas and Propagation Society, the U. S. National Committee of the International Union of Radio Science, and the Permanent NEM Committee, I would like to welcome all of the conference participants to the University of New Mexico for what is expected to be an outstanding conference.

I would like to thank the University of New Mexico for being a very capable and gracious host. Special thanks and recognition is also due to the conference committee which was divided into several major parts. Besides the arrangements committee there were three technical committees, one for each of the sponsoring groups. The Albuquerque Convention and Visitors Bureau provided considerable assistance with the housing as well as other matters.

There is plenty for everyone to do at this conference. There are roughly 500 papers to choose among; there is a very interesting plenary session on Wednesday morning; there are business meetings of various groups and various social events and tours. Of course there is also the banquet Wednesday evening. Consult your program and watch the registration area for bulletins.

I wish all of you a most productive conference and one that you will wish to remember in future years.

Dr. Carl E. Baum
Conference Chairman

SYMPOSIUM COMMITTEES

CHAIRMAN
C.E. Baum

ARRANGEMENTS COMMITTEE
K.S. Kunz, Chairman
D.E. Merewether, Vice Chairman
H.J. Wagnon, Treasurer
L.W. Chen, Publicity
R.W. Shoup, Publications/Publicity
J. Wagner, Publications
A. Agrawal, Publications
R. Gardner, Thours
S.H. Gurbaxani, Facilities
G. Sower, Institutional Facilities
T. Kohlman, Local Affairs
Registration Committee:

P. Baca	A. Merewether
M. Carroll	E. Merewether
R. Fisher	M. Scales
H.A. Goodwin	V. Wolf
P. Hedlund	

TECHNICAL PROGRAM COMMITTEES:
GENERAL COORDINATION
C.E. Baum
C.W. Jones

USNC/URSI
K.F. Casey, Representative
C.M. Butler, Comm. B Chairman
A.A. Giordano, Comm. E Chairman
E.E. Gossard, Comm. F Chairman

IEEE/AP-S
K.F. Casey, Co-Chairman
B.K. Singaraju, Co-Chairman

W. Boerner	R. Mittra
C.M. Butler	D. Moffatt
D. Dudley	W. Pearson
L. Felsen	R. Pogorzelski
S.H. Gurbaxani	Y. Rahmat-Samii
R.C. Hansen	T. Senior
R. Harrington	L.C. Shen
D. Hill	W.R. Stone
R. Hutchins	C. Swift
A. Ishimaru	F. Tesche
R. Kouyoumjian	P.L.E. Uslenghi
A. Love	J. Wait
K. Mei	C. Yeh
E. Miller	

NEM
K.C. Chen, Co-Chairman
L.D. Scott, Co-Chairman

M.D. Bradshaw	K.S.H. Lee
R. Carlile	L.F. Libelo
J.P. Castillo	J.V. Locasso
K. Enkenhaus	C.L. Longmire
T.M. Flanagan	L. Marin
P. Fleming	D.E. Merewether
J. Gilbert	M.E. Morris
D.V. Giri	R.L. Parker
D.F. Higgins	W.E. Page
W.J. Karzas	I.D. Smith
W.S. Kehrer	C.D. Taylor
K.S. Kunz	E.F. Vance

SPONSORS: Institute of Electrical and Electronic Engineers--Antennas and Propagation Society

U.S. National Committee of the International Union of Radio Science (USNC/URSI)--
Commission B: Fields and Waves
Commission E: Interference Environment
Commission F: Wave Phenomena in Non-Ionized Media

Permanent NEM Committee--

In cooperation with the following government agencies:

Harry Diamond Laboratories
Naval Surface Weapons Center
Air Force Weapons Laboratory
Defense Nuclear Agency

and in cooperation with

The Electromagnetics Society

HOST: The University of New Mexico

MEMBERSHIP

United States National Committee

INTERNATIONAL UNION OF RADIO SCIENCE

Chairman:	Prof. Thomas B.A. Senior*
Vice Chairman:	Prof. Robert K. Crane*
Secretary:	Dr. Thomas E. VanZandt*
Immediate Past Chairman:	Dr. C. Gordon Little*

Members Representing Societies, Groups and Institutes:

American Geophysical Union	Dr. Christopher T. Russell
Bioelectromagnetics Society	Dr. James C. Lin
Institute of Electrical & Electronic Engineers	
IEEE Antennas & Propagation Society	Dr. Alan W. Love
IEEE Communications Society	Prof. Raymond Pickholtz
IEEE Electromagnetic Compatibility Society	
IEEE Information Theory Group	
IEEE Microwave Theory & Techniques Society	
IEEE Quantum Electronics Society	Prof. Herman A. Haus
Optical Society of America	Dr. Steven F. Clifford

Liaison Representatives from Government Agencies:

National Telecommunications & Information Administration	Dr. Douglass D. Crombie
National Science Foundation	Dr. Vernon Pankonin
Department of Commerce	
National Aeronautics & Space Administration	Dr. Erwin R. Schmerling
Federal Communications Commission	Mr. William A. Daniel
Department of Defense	Dr. George L. Salton
Department of the Army	Lt. Col. Robert Clayton, Jr.
Department of the Navy	Dr. Leo Young
Department of the Air Force	Dr. Allan C. Schell

Members-at-Large:	Dr. Sidney A. Bowhill
	Dr. Juergen E. Richter
	Dr. George W. Swenson, Jr.

*Member of USNC-URSI Executive Committee

Chairmen of the USNC-URSI Commissions:

Commission A	Dr. Helmut Hellwig
Commission B	Prof. Chalmers M. Butler
Commission C	Dr. Andrew J. Viterbi
Commission D	
Commission E	Dr. Arthur A. Giordano
Commission F	Dr. Earl E. Gossard
Commission G	Dr. Kenneth Davies
Commission H	Dr. Robert F. Benson
Commission J	Prof. Mark A. Gordon

Officers of URSI resident in the United States:
(including Honorary Presidents)

President	Prof. William E. Gordon*
Honorary President	Prof. Henry G. Booker*

Chairmen and Vice Chairmen of Commissions of URSI resident in the United States:

Chairman of Commission C	Prof. Jack K. Wolf
Vice Chairman of Commission G	Dr. Jules Aarons

Foreign Secretary of the U.S. National Academy of Sciences	Dr. Thomas F. Malone
Chairman, Office of Physical Sciences-NRC	Prof. William A. Fowler
NRC Staff Officer	Mr. Richard Y. Dow
Honorary Members:	Dr. Harold H. Beverage Prof. Arthur H. Waynick Dr. Ernst Weber

*Member of USNC-URSI Executive Committee

DESCRIPTION OF THE

INTERNATIONAL UNION OF RADIO SCIENCE

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

The officers of the International Union are:

President	W. E. Gordon (USA)
Past President:	W. N. Christiansen (Australia)
Vice Presidents:	A. L. Cullen (U.K.) A. P. Mitra (India) S. Okamura (Japan) A. Smolinski (Poland)
Secretary-General:	J. Van Bladel (Belgium)
Honorary Presidents:	H. G. Booker (USA) G. Beynon (U.K.) M. B. Decaux (France) W. Dieminger (West Germany) I. Koga (Japan) J. A. Ratcliffe (U.K.)

The Secretary-General's office and the headquarters of the organization are located at Avenue de Lancaster 32, B-1180 Brussels, Belgium. The Union is supported by contributions (dues) from 38 member countries. Additional funds for symposia and other scientific activities of the Union are provided by ICSU from contributions received for this purpose from UNESCO.

The International Union as of the XXth General Assembly held in Washington, D.C. in August 1981, has nine bodies called Commissions for centralizing studies in the principal technical fields. The names of the Commissions and their chairmen follow.

A. Electromagnetic Metrology
V. Kose (FRG)

B. Fields and Waves
H. C. Unger (FRG)

C. Signals and Systems
J. K. Wolf (USA)

D. Electronic and Optical Devices and Applications
J. Le Mezec (France)

E. Electromagnetic Noise and Interference
S. Lundquist (Sweden)

F. Remote Sensing and Wave Propagation
D. Gjessing (Norway)

G. Ionospheric Radio and Propagation
P. Bauer (France)

H. Waves in Plasmas
M. Petit (France)

J. Radio Astronomy
V. Radhakrishnan (India)

Every three years the International Union holds a meeting called the General Assembly and the next is the XXIst, to be held in Florence, Italy, in August/September, 1984. The Secretariat prepares and distributes the Proceedings of these General Assemblies. The International Union arranges international symposia on specific subjects pertaining to the work of one Commission or to several Commissions, and also cooperates with other Unions in international symposia on subjects of joint interest.

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

CONTENTS

PLENARY SESSION
WEDNESDAY 8:30-11:20
STUDENT UNION BALLROOM

Chairman: K. S. Kunz
Kunz Associates, Inc.
Albuquerque, NM

SESSION URSI-B-1 MEDIA INTERFACE EFFECTS
MONDAY 8:30-9:50
EDUCATION CENTER, Room 103

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

SESSION URSI-B-2 APERTURE THEORY
MONDAY 10:40-12:00
EDUCATION CENTER, Room 103

Chairman: A. W. Glisson
University of Mississippi
University, MS

SESSION URSI-B-3
MONDAY 8:30-12:20
EDUCATION CENTER, Room 101

Chairman: A. Hessel
Polytechnic Institute of New York
Farmingdale, NY

SESSION URSI-B-4/AP-7 GEORGES DESCHAMPS SESSION
MONDAY 1:45-5:00
EDUCATION CENTER, Room 103

Chairman: L. B. Felsen
Polytechnic Institute of New York
Farmingdale, NY

SESSION URSI-B-5
TUESDAY 8:30-12:00
EDUCATION CENTER, Room 103

ELECTROMAGNETIC THEORY

Chairman: W. A. Johnson
Lawrence Livermore National Laboratory
Livermore, CA

SESSION URSI-B-6
TUESDAY 8:30-11:40
EDUCATION CENTER, Room 101

PROPAGATION THEORY

Chairman: A. Q. Howard
University of Arizona
Tucson, AZ

SESSION URSI-B-7
TUESDAY 1:30-4:00
EDUCATION CENTER, Room 103

HIGH FREQUENCY TECHNIQUES (GTD)

Chairman: P. H. Pathak
Ohio State University
Columbus, OH

CONTENTS

PLENARY SESSION
WEDNESDAY 8:30-11:20
STUDENT UNION BALLROOM

Chairman: K. S. Kunz
Kunz Associates, Inc.
Albuquerque, NM

SESSION URSI-B-3
MONDAY 8:30-12:20
EDUCATION CENTER, Room 101

Chairman: A. Hessel
Polytechnic Institute of New York
Farmingdale, NY

SESSION URSI-B-4/AP-7 GEORGES DESCHAMPS SESSION
MONDAY 1:45-5:00
EDUCATION CENTER, Room 103

Chairman: L. B. Felsen
Polytechnic Institute of New York
Farmingdale, NY

SESSION URSI-B-5
TUESDAY 8:30-12:00
EDUCATION CENTER, Room 103

ELECTROMAGNETIC THEORY

Chairman: W. A. Johnson
Lawrence Livermore National Laboratory
Livermore, CA

SESSION URSI-B-6
TUESDAY 8:30-11:40
EDUCATION CENTER, Room 101

PROPAGATION THEORY

Chairman: A. Q. Howard
University of Arizona
Tucson, AZ

SESSION URSI-B-7
TUESDAY 1:30-4:00
EDUCATION CENTER, Room 103

HIGH FREQUENCY TECHNIQUES (GTD)

Chairman: P. H. Pathak
Ohio State University
Columbus, OH

SESSION URSI-B-8 NUMERICAL METHODS
TUESDAY 1:30-5:00
EDUCATION CENTER, Room 101

Chairman: W. A. Davis
Virginia Polytechic Institute and State University
Blacksburg, VA

SESSION URSI-B-9 SCATTERING
WEDNESDAY 1:30-5:00
EDUCATION CENTER, Room 103

Chairman: R. J. Pogorzelski
TRW
Redondo Beach, CA

SESSION URSI-B-10 ANTENNA THEORY
WEDNESDAY 1:30-5:00
EDUCATION CENTER, Room 101

Chairman: S. A. Long
University of Houston
Houston, TX

SESSION URSI-E-5/URSI-B-11/NEM-12
WEDNESDAY 1:30-3:30
EDUCATION CENTER, Room 104

SCIENTIFIC BASIS FOR NOISE AND INTERFERENCE CONTROL

Chairman: E. Vance
SRI International
Menlo Park, CA

SESSION URSI-B-12 INVERSE SCATTERING I
THURSDAY 8:30-11:20
EDUCATION CENTER, Room 103

Chairman: A. K. Jordan
Naval Research Laboratory
Washington, DC

SESSION URSI-B-13 TRANSIENTS AND SEM
THURSDAY 8:30-12:00
EDUCATION CENTER, Room 101

Chairman: C. D. Taylor
Mississippi State University
Mississippi State, MS

SESSION URSI-B-14 INVERSE SCATTERING II
THURSDAY 1:30-4:20
EDUCATION CENTER, Room 103

Chairman: D. L. Jaggard
University of Pennsylvania
Philadelphia, PA

SESSION URSI-B-15
FRIDAY 8:30-12:00
EDUCATION CENTER, Room 103

ANTENNA THEORY II: MICROSTRIP

Chairman: G. Smith
Georgia Institute of Technology
Atlanta, GA

SESSION URSI-E-1/NEM-3 LIGHTNING I
MONDAY 8:30-10:10
EDUCATION CENTER, Room 204

Chairman: C. Moore
New Mexico Institute of Technology
Socorro, NM

SESSION URSI-E-2
MONDAY 3:40-5:00
EDUCATION CENTER, Room 204

SHIELDING

Chairman: A. Giordano
GTE Sylvania
Needham, MA

SESSION URSI-E-3/NEM-8 LIGHTNING II
TUESDAY 8:30-11:00
EDUCATION CENTER, Room 204

Chairman: K. Zeisel
McDonnell Aircraft Company
St. Louis, MO

SESSION URSI-E-4
TUESDAY 1:30-5:00
EDUCATION CENTER, Room 204

NOISE MEASUREMENTS AND INTERACTION

Chairman: J. R. Herman
GTE Sylvania
Needham, MA

SESSION URSI-E-5/URSI-B-11/NEM-12
WEDNESDAY 1:30-3:30
EDUCATION CENTER, Room 104

SCIENTIFIC BASIS FOR NOISE AND INTERFERENCE CONTROL

Chairman: E. Vance
SRI International
Menlo Park, CA

SESSION URSI-F-1
MONDAY 1:30-4:20
EDUCATION CENTER, Room 204

REMOTE SENSING OF THE ENVIRONMENT

Chairman: E.R. Westwater
NOAA/ERL, WPL
Boulder, CO

SESSION URSI-F-2
THURSDAY 8:30-11:20
EDUCATION CENTER, Room 204

PROPAGATION I

Chairman: E. Bahar
University of Nebraska
Lincoln, NE

SESSION URSI-F-3
THURSDAY 1:30-4:00
EDUCATION CENTER, Room 204

PROPAGATION II: SATELLITE SYSTEMS

Chairman: J. R. Wait
University of Arizona
Tucson, AZ

SESSION URSI-F-4
FRIDAY 8:30-11:00
EDUCATION CENTER, Room 204

PROPAGATION III

Chairman: D. A. Hill
NTIA/ITS2
Boulder, CO

THE MAYPOLE (HOOP/COLUMN) ANTENNA DEVELOPMENT PROGRAM

by

Thomas G. Campbell and David H. Butler

Langley Research Center

INTRODUCTION

The Maypole hoop/column antenna concept is a deployable space frame that has the potential capability of providing several different reflector surface contour designs from the same basic configuration. Therefore, this concept was selected for development to a feasibility level by the Langley Research Center (LaRC) during the Advanced Application Flight Experiment (AAFE) Program. But now, more detailed design and analytical activities (coupled with hardware verification tests) are underway through the Large Space Antenna (LSA) Program at LaRC. The hoop/column point deployed design configuration is shown in Figure 1 and the stowed geometry configuration is shown in Figure 2. Since the applicability of the hoop/column concept with respect to the antenna focus missions is of utmost concern, the results of the mission scenario activity strongly influenced the selection of the baseline configuration--the point design for the LSA Program. Basically, the communication mission scenario was adjudged to contain a significant number of technology drivers; so, the baseline configuration for the hoop/column was selected on that basis. Therefore, it was imperative that the hoop/column antenna be configured so that the requirements associated with the communication mission (beams using offset feed reflectors) would be addressed. Hence, a significant difference between the LSA effort and the previous AAFE study is in the antenna feed configuration that is required for the hoop/column reflector.

During the AAFE study, axisymmetric feed configuration (F/D < 1) were used; but emphasis is now placed on asymmetric feed configurations. So a multiple aperture concept (F/D > 1) using offset feed configurations was introduced using the hoop/column design. The multiple aperture approach has led to a quad aperture point design for subsequent hardware development. The quad aperture concept is generated by defining a separate reflector surface in each quadrant of the basic antenna surface. This concept appears to be very promising as several offset fed apertures could be provided within the same antenna structure. The focal point for each quadrant reflector is totally offset so that the feed system does not block the aperture. With this multiple aperture approach, the area now available for the feed array elements has been increased significantly. To meet multiple beam requirements, 55 beams could illuminate each quad reflector to produce a total of 220 beams from the entire system. Each feed array will be attached to the central column and beam interleaving is adjusted by translating the feed array in two dimensions. This approach should effectively scan the beams and fix the beam-to-beam crossover points at the desired levels. The total structural size for the offset geometry is the same for the symmetrical configuration so that F/D for the offset reflector is essentially doubled.

The use of the quad aperture hoop/column antenna configuratior could also require innovative mesh designs for the reflective surfaces. For example, multiple meshes will be required throughout the quad reflector for the following reasons: first, an open mesh (transparent at the operating wavelength) will be used on the main portion of the reflector but outside the respective illuminated regions. This would allow side lobe energy to leak through the outside region of the reflector. Secondly, the reflector mesh system could accommodate dual frequency operation (C-band and Ku-band) by using frequency selective surface (FSS) techniques, the FSS material in each quad aperture would allow for the wavelength differences (2.5) and produce equivalent beamwidths at each frequency.

Therefore, it can be seen that the quad aperture hoop/column concept is more complex than a symmetrical configuration and, indeed, more challenging from an antenna design standpoint. Also, the technology that is developed through the LSA Program should be more beneficial. The critical parameters selected for the 100-meter point design quad aperture configuration are listed below:

- 100-meter diameter parent reflector,
- Quad offset apertures--40.6 meters, in diameter each,
- F/D = 1.53,
- Focal length (single offset)--62.12 meters,
- Frequency for the point design--2.0 GHz
- Half power beam width--0.256°,
- 220 beams, 55 beams/aperture,
- Surface accuracy--$\lambda/20$,
- Beam to beam isolation--30 dB,
- Gain--55.4 dB, and
- Point accuracy--0.03°

CONCEPT DEVELOPMENT PROGRAM

The Hoop/Column Development Program at LaRC will complete the design and conduct design verification tests to prove that the multiple aperture concept can provide efficient multiple beam performance characteristics. After completing the numerous LSA activities, it will then be possible to evaluate this concept through meaningful trade-off studies. Recognizing the fact that smaller deployable designs do not adequately identify problems associated with large antennas, the technology efforts are focused on the following issues:

- Development and demonstration of hoop/column reflector technology to satisfy focus mission requirements;

- Verfication of the analytical technique for predicting reflector performance,
- Development and verification of scaling relationships that allow extrapolation of performance to a wide range of antenna sizes,
- Development and verification of design analytical and control methods for reflector surface adjustment techniques,
- Development and demonstration of measurement systems to allow orbital evaluation of the reflector contour, including integrated demonstration of these measurement systems with the reflector,
- A verified parametric cost model for each large antenna system, and
- Verified techniques and procedures for the manufacture, assembly, and testing of large antenna systems.

EXPERIMENT MODELS

Efforts with the concept development program area will: (1) provide hoop/column scaled hardware models which satisfy the focus mission configuration requirements, and (2) identify critical hoop/column components. This will be accomplished by building full-scale components and subscale engineering verification models where necessary. The verification models will:

- Establish fabrication and assembly procedures for large size, cable supported, mesh reflectors,
- Demonstrate that large scale mesh reflectors can be built to a prescribed curvature within acceptable tolerances,
- Establish the surface shape to the desired contour and establish if inflight adjustments of the surface are necessary,
- Determine the compatibility of an engineering in-flight surface accuracy measurement system (SAMS) with the hoop/column design,
- Compare experimental results of surface setting and adjusting on the model with analytical predictions of surface accuracy and surface improvements to cable adjustment,
- Establish ground handling procedures for folding the hoop, mesh, cables, and mast into the stowed position,
- Demonstrate the deployment kinematics of the hoop, mesh, cables, and mast during the deployment sequence,
- Measure the surface accuracy of a mesh surface after deployment, and
- Establish the effects of cable blockage on the RF performance of the antenna.

There are three major engineering models planned for the hoop/column technology development program: (1) a 50-meter surface adjustment model, (2) a 15-meter deployment antenna model, and (3) an RF verification model. These models will be developed in accordance with the plan referred to earlier.

CONCLUDING REMARKS

The development of the hoop/column antenna is ongoing. A 4-gore section of a 50-meter diameter reflector has been fabricated and tested. Plans are now underway for the development and tests of the 15-meter diameter kinematic reflector model. The 15-meter model development is planned to be completed in (FY) 1984. The results of the hoop/column development program will provide analysis methods that will be validated using subscale reflector models. The successful conclusion of these activities will provide NASA the capability to conduct meaningful trade-off studies for large space antenna applications. These studies would include risk-assessment, performance prediction (RF and structural) and, antenna costs projections. Also, definition activities for a large antenna flight experiment could then be made using known antenna capabilities.

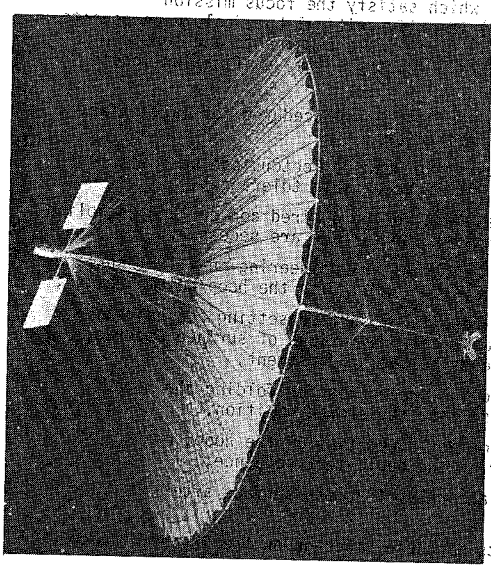


Figure 1. Deployed Configuration of the Maypole Hoop/ Column Antenna Concept.

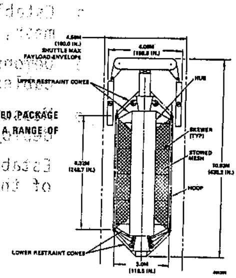


Figure 2. Stowed Configuration of the Maypole Hoop/Column Antenna.

PULSED POWER TECHNOLOGY AT SANDIA NATIONAL LABORATORIES

G. Yonas
Sandia National Laboratories
Albuquerque, NM 87185

Pulsed power in the U.S. has progressed substantially over the last fifteen years based on support from the D.O.D. and D.O.E. for near term defense and long term energy applications. Sandia began its effort with Hermes II which was developed in collaboration with the A.W.R.E. This gamma-ray simulator has been an active part of the D.O.E. weapons effects testing program with 20,000 shots since 1967. An advanced simulator, Hermes III, now under prototype development, will provide improved dose-rate and larger area testing capabilities. Hermes III will encompass many of the developments from the D.O.E. inertial fusion program as embodied in PBFA-I as well as from the A.F.W.L./Sandia multi-stage accelerator technology program, RADLAC.

PBFA-I, a 36 module, 2 MV, 30 TW accelerator began operation in 1980 and is currently being employed to investigate voltage addition and ion diode scaling using magnetically insulated reconnection. PBFA-II, with 36 modules and a 100 TW output, will be configured to allow its use, beginning in 1986, as either an ion accelerator at 10 MV or an imploding foil driver at 30 MA.

RADLAC I has produced a 25 kA, 9 MeV electron beam through post acceleration of a 2 MeV beam by four radial pulse line driven cavities. RADLAC II, now under construction, will allow us to explore the extension of this approach to higher currents and voltages. Other activities include development of repetitive pulse components, low jitter switching, multi-stage and collective ion acceleration, and explosive power supplies with fast opening switches.

With the inception of modular, multi-stage pulseline techniques and methods for voltage or current addition, pulsed power has opened up a new dimension in power concentration. With the inevitable future improvements in compact pulse forming and energy storage, synchronized switching, and breakdown suppression, the opportunities for further application of pulsed power will accelerate.

THE NUCLEAR ELECTROMAGNETIC PULSE PROGRAM: EVOLUTION AND IMPACT ON TECHNOLOGY

Dr. J. Philip Castillo
Air Force Weapons Laboratory/NTYE
Kirtland Air Force Base, New Mexico 87117

This paper will present the evolution of the technical developments in nuclear electromagnetic pulse (EMP) technology and its dependence on and relationship to electromagnetics. This technical area includes the physics of generation of the EMP, the interaction of EMP with objects as well as methods for the simulation of the EMP. General methods for testing and protecting electronic equipment will be discussed.

The EMP program impact on the electromagnetic technology will be presented including instrumentation and theoretical aspects. A history of the EMP technology development will be included.

AIR FORCE HIGH ENERGY LASER PROGRAM

by

JAMES D. DILLOW
AIR FORCE WEAPONS LABORATORY
KIRTLAND AIR FORCE BASE, NEW MEXICO

Abstract

The purpose of this presentation is to describe selected technical aspects of the Air Force Weapons Laboratory's high energy laser program. The presentation is introduced with a film of the Delta experiment, where a drone aircraft was destroyed in the air by a high energy laser. In order to put the technology programs in perspective, a generic high energy laser weapon system is discussed and the Air Force Weapons Laboratory technology program is overviewed.

The technology areas are selected for further description -- devices and beam control. First, the laser devices that are being developed by the Air Force Weapons Laboratory are briefly described. In order to describe the Air Force Weapons Laboratory beam control technology program, a state-of-the-art beam control system is compared to a generic advanced beam control concept. The reliance on adaptive optics in advanced systems is pointed out and two adaptive optics systems being studied by the Air Force Weapons Laboratory are selected for further description.

RECENT OBSERVATIONS WITH THE VLA RADIO TELESCOPE

R. A. PERLEY NATIONAL RADIO ASTRONOMY OBSERVATORY

The VLA (Very Large Array) is the world's most powerful and flexible radio telescope. Situated on a high plain in western New Mexico, the VLA was built by the National Radio Astronomy Observatory, and is designed to provide high quality maps of celestial radio sources. Comprising 27 25- meter parabaloidal reflectors, the instrument provides maps of the sky visible within the antenna primary beam through Fourier inversion of the 351 cross-correlations. It operates in any of four bands, centered roughly near 1.5, 5, 15 and 23 GHz, with a sensitivity of up to 10^{-31} watt m^{-2} Hz^{-1} at the two lower bands, and with a resolution, at 5 GHz, of $\sim$0.3". The VLA can operate in a continuum mode, with bandwidths of up to 50 MHz, or in spectral line mode with up to 256 channels with frequency resolution selectable from 12.5 MHz to 400 Hz.

The VLA was dedicated in October, 1980, and since then has been used by astronomers from around the world to map a wide range of astronomical objects. These may be classified in three groups:

A) Solar and Planetary. Maps of the active and quiet sun, and of most of the planets, have now been made.

B) Galactic. Our galaxy contains a very wide assortment of radio emitting objects and regions. Objects observed at the VLA include stars, planetary nebulae, supernova remnants, molecular clouds, the galactic center, HII regions and exotic objects such as SS433.

C) Extragalactic Beyond our galaxy lies inmumerable radio emitting objects, including normal galaxies, Seyfert galaxies, radio galaxies and quasars. These ofter appear very differently in the radio region of the spectrum than do the optical objects, and have been the subject of much VLA observing time.

In the talk, many of the latest observations from these and other astronomical objects will be shown, and the scientific implications briefly discussed.

SURFACE CHARGE AND CURRENT DENSITIES ON A VERTICAL PERFECTLY CONDUCTING CYLINDER PENETRATING THE AIR EARTH INTERFACE*

W. A. Johnson
Lawrence Livermore National Laboratory
Livermore, CA 94550

D. G. Dudley
University of Arizona
Tucson, AZ 85721

Applications of the Numerical Electromagnetics Code (G. J. Burke and A. J. Poggio, NOSC TD 116, Jan. 1981) to the analysis of thin wires penetrating the air-earth interface requires a characterization of the behavior of both the wire's surface charge and surface current densities at the air-earth interface. A brief analysis shows that the current density is continuous across the interface. The ratio of the charge density in the earth just below the interface to the charge density in air just above the interface is equal to the earth's relative dielectric constant.

To obtain a detailed knowledge of the charge and current densities near the interface the boundary value problem for a vertical cylinder penetrating the air-earth interface is solved. To avoid excessive complications an azimuthally symmetric excitation is chosen. The resulting system of integral equations is put in a form similar to those used by Glisson and Wilton to analyze a stepped-radius antenna (A. W. Glisson and D. R. Wilton, "An Accurate Numerical Investigation of the Stepped-Radius Antenna", National Radio Science Meeting, Boulder, Colorado, Nov. 1978). The charge and current densities on a tubular cylinder are first considered. Next a solid cylinder with end caps is studied to quantify "how thin is thin enough for thin wire theory to hold in a lossy medium".

---

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

SCATTERING FROM A CONDUCTING STRIP EMBEDDED IN A DIELECTRIC SLAB

K. A. Michalski
C. M. Butler
Department of Electrical Engineering
University of Mississippi
University, MS 38677

The purpose of this paper is to report upon an investigation of scattering of a specified incident field by a conducting strip which resides in an infinite dielectric slab of uniform thickness. The strip is at the slab center and is parallel to its faces. The slab with embedded strip is in a homogeneous open space whose electromagnetic properties are different from those of the slab. Excitation is transverse magnetic to and invariant along the strip axis but otherwise may be general. An integral equation whose kernel contains a two-dimensional Sommerfeld-type integral is formulated for the strip current and is solved numerically. Care is given to accurate and efficient evaluation of the Sommerfeld integral; different evaluation schemes are described and compared. Current distributions for several cases of interest are presented and are interpreted physically. Far-zone field patterns, determined by asymptotic techniques, are given for various combinations of strip widths, slab thicknesses, and slab material parameters.

LORAN-C POSITIONING ERRORS CAUSED BY SCATTERING FROM POWER LINES ABOVE THE EARTH

Robert G. Olsen and Abdulmagid Aburwein
Department of Electrical Engineering
Washington State University, Pullman, WA 99164

In this paper the scattering of a LORAN-C navigation signal by a power line is calculated. The results of the derivation can be used to predict positioning errors for land based applications of LORAN-C such as vehicle location schemes. The only assumptions are that the line spacing is small compared to its height and that the LORAN-C signal is narrowband, and not incident at a grazing angle. From this general result a very simple theory for predicting positioning errors is derived which is valid for most parameters of interest. The simple result for the error in pulse arrival time is

$$\Delta t = \frac{\sqrt{2}\, d \tan^2 \theta_p}{\omega_o |n| \ln(2d/a) k_o (d^2 + y^2)}$$

where a is the equivalent radius of the power line conductors
d is the average height of the power line conductors
y is the distance of the receiver from the power line
$\theta_p = \pi/2 - \phi$ where ϕ is the angle between the power line and the direction to the LORAN transmitter
ω_o is the center radian frequency of the pulse
k_o is the propagation constant of free space
$|n|$ is the refractive index of the earth

It is found that, when a LORAN-C receiver is located near a power line, position errors of 1 Kilometer are possible. This value is in accord with published experimental results. Further, it is shown that position errors are significantly greater when the LORAN-C signal approaches the transmission line at a small angle.

FAR-FIELD COMPUTATIONS INSIDE A DIELECTRIC MEDIA FOR AN ANTENNA ABOVE A PLANAR INTERFACE

Richard L. Lewis, Electromagnetic Fields Division
National Bureau of Standards, Boulder, Colorado 80303

We wish to consider the problem of an aperture antenna located a distance d above a planar dielectric interface, where we are interested in determining the far field at a distance r inside the dielectric media as the ratio r/d gets large but not necessarily infinite. From the plane-wave-spectrum representation of an antenna above a planar interface, we carry out an asymptotic saddle-point evaluation of the plane-wave integral to obtain the far-field. The dielectric boundary causes a shift in the saddle-point location as compared to the single media location. We find that the saddle-point location is obtained by solving two coupled transcendental equations, for which a geometrical optics interpretation is readily apparent so long as one is not within the evanescent-mode domain of the integral.

If the antenna is located fairly close to the interface, then it is valid to use the single-media saddle-point location as a first order approximation to the transcendental saddle-point equation. One surprising result is that transmission into the dielectric media does not diminish as grazing incidence is approached. However, if the antenna is located at least a few wavelengths above the interface, then as the angle of incidence changes from grazing towards evanescence these waves will become highly attenuated. Thus the field radiated into the dielectric media rapidly attenuates for angles of refraction greater than the "cut-off" angle corresponding to grazing incidence. If the antenna is very close to the interface, then the evanescent waves can contribute appreciably to the field radiated into the dielectric media; consequently, analysis of this case requires a knowledge of the antenna's reactive field. In the special case of a truncated parallel plate waveguide, the complete spectrum is known exactly (cf. Montgomery & Chang, NBS Monograph 164, June 1979). It is interesting to speculate on whether constrained planar source synthesis (cf. Rhodes, Synthesis of Planar Antenna Sources, 1974) can be used to estimate the reactive field contribution in cases where only the measured field is used to characterize the antenna.

Computations have been carried out for the specific case of an open-ended rectangular waveguide located far enough above the interface that evanescent waves could be neglected. Here, a variant of Chu's formula for the field radiated by an open-ended waveguide was used so that the formulation could be expressed in closed form. However, the price for analytical simplicity is that our formulation neglects higher-order modes in the waveguide aperture that are excited by reflections from the interface and the abrupt waveguide termination. Our computations are compared to measured data obtained by illuminating a hemisphere filled with sand and measuring the field strength underneath the hemisphere.

A MOMENT SOLUTION FOR ELECTROMAGNETIC COUPLING THROUGH A SMALL APERTURE

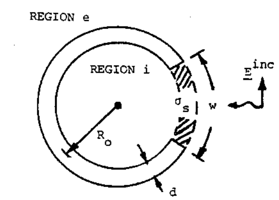
Roger F. Harrington and Joseph R. Mautz
Department of Electrical and Computer Engineering
Syracuse University
Syracuse, NY 13210

A three term moment solution for electromagnetic coupling through a small aperture in a conducting screen is obtained. This solution gives the equivalent magnetic current in the aperture as a linear combination of the three quasi-static magnetic currents responsible for the three dipole fields seen in the far zone. Because only the dipole effects of the quasi-static currents are known, the elements of the excitation vector and the moment matrix can not be evaluated directly. Reciprocity is used to express the elements of the excitation vector in terms of the short-circuit incident fields. The imaginary parts of the elements of the moment matrix are evaluated by forcing the moment solution to be equal to the solution predicted by conventional small aperture theory. The real parts of the elements of the moment martrix are extracted from the quadratic expression for the power radiated by the magnetic current. The solution is applied to three examples - an aperture in a conducting plane, an aperture in a transverse wall between two rectangular waveguides, and an aperture in a lateral wall of a rectangular waveguide coupling to a half-space.

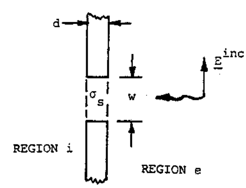
EQUIVALENT CIRCUIT ANALYSIS OF ELECTROMAGNETIC TRANSMISSION THROUGH A FILLED SLOT IN A THIN-WALLED CYLINDER

D.T. Auckland
Syracuse Research Corporation
Syracuse, NY 13210

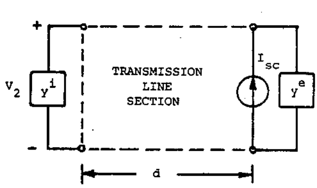
An equivalent circuit is postulated and its parameters are derived for a filled slot in a thin-walled conducting cylinder. The one-term moment method (R.F. Harrington and D.T. Auckland, IEEE Trans. on A.P., September 1980) is employed. Here a lumped admittance is used to represent an external region (Region e) and an interior region (Region i). The slot region (Region s) is treated as a parallel-plate waveguide section. The analytical results obtained are compared to those for a slotted infinite screen and the importance of the inductive susceptance, caused by the circular shell interior, on the slot transfer admittance, Y_T, is noted.



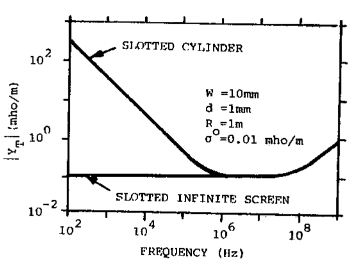
(a) Slotted Circular Shell, $k_oR_o<<1$, $k_ow<<1$



(b) Slotted Infinite Screen, $k_oW<<1$



(c) Equivalent Circuit for (a) and (b)



(d) Plot of $Y_T = I_{sc}/V_2$ Versus Frequency for (c)

CAPACITIVE AND INDUCTIVE IRISES IN RECTANGULAR WAVEGUIDE: A NEW SOLUTION

Kendall F. Casey
Lawrence Livermore National Laboratory
P. O. Box 5504, L-156
Livermore, CA 94550

Techniques for the solution of dual series equations arising in potential theory are extended and applied to the solutions of two classical problems in waveguide theory: the capacitive and inductive iris problems. It is found that the normalized iris susceptances can be obtained from a rapidly convergent set of linear equations in the modal amplitudes and that new approximate expressions can be obtained from these equations by analytical means. The key to the procedure is expressing the modal amplitudes in terms of certain Jacobi polynomials. Numerically exact and approximate results are presented and compared, both against each other and against extant approximate results obtained by variational means. Applications of the method to other guided-wave problems of more current interest are also discussed.

SEAM COUPLING USING THE FINITE DIFFERENCE METHOD AND THE GENERALIZED BABINET PRINCIPLE

Karl S. Kunz, Kunz Associates, Inc., Albuquerque, N.M.

While finite difference methods have modeled relatively fine detail in electromagnetic coupling problems involving aerospace systems, they have not modeled coupling through thin seams such as arise from composite panel construction. Cell size, characterized by dimensions on the order of a meter, would have to shrink to a millimeter or less. Such a reduction cannot be expected anytime soon.

A solution to this problem does exist that combines the finite difference method with the generalized Babinet principle [Jordan and Balmain, Electromagnetic Waves and Radiating Systems, pp. 519-22]. First, the interaction object is treated without seams, using the finite difference method. Aperture and diffusive coupling can be treated with current versions of the method. Having treated these effects, the interaction object can now be considered a perfectly conducting surface segmented by seams into panels. Thus, second, the interaction object geometry can be replaced by a conjugate/complement geometry where the perfectly conducting panels, which represent the scattering surface, are replaced by the boundary condition $\vec{n} \times \vec{H}^{scattered} = 0$, seams are replaced by wires, and electrically conducting structures ($\vec{n} \times \vec{E}^{total} = 0$) on either side of the scattering surface are changed to magnetic conductors ($\vec{n} \times \vec{H}^{total} = 0$). Thin wires can be accurately modeled [Holland, IEEE Trans. EMC, pp. 88-97,1981] using finite difference techniques. This allows the accurate calculation of the fields scattered from the conjugate/complement model, $H^{total}_{icc} = H^{inc}_{icc} + H^{scattered}_{icc}$ and $E^{total}_{icc} = E^{inc}_{icc} + E^{scattered}_{icc}$. The generalized Babinet principle states that

$$U_1+U_2 = \frac{H_i^{total}}{H_i^{inc}} + \frac{E_{icc}^{total}}{E_{icc}^{inc}} = 1 \text{ or } H_i^{total} = \frac{-H_i^{inc}}{E_{icc}^{inc}} E_{icc}^{scattered}$$

From these relations the fields scattered from the conjugate/complement model can be converted into the fields, $H_i^{total} = H_i^{inc} + H_i^{scattered}$ and $E_i^{total} = E_i^{inc} + E_i^{scattered}$, scattered by the seams, completing the problem.

MICROSTRIP FEEDING VIA A SLOTTED RECTANGULAR WAVEGUIDE

Perry F. Wilson and David C. Chang,
Electromagnetics Laboratory
Department of Electrical Engineering
University of Colorado
Boulder, Colorado 80309

As the operating frequency of a microstrip increases, conventional excitation with a coaxial pin feeding becomes physically more difficult and a mode launching method more compatible with planar construction techniques becomes increasingly desirable. An alternate approach, investigated in this paper, is to couple a microstrip to a rectangular waveguide at the groundplane via a narrow slot running longitudinally in the direction of propagation. The coupling strength will be affected by the slot location, or offset, as well as the slot width. Numerical results for these gap dependencies, as well as guide matching considerations, will be discussed.

Previous work by the authors has dealt with how the requirement of constructive interference leads to the formulation of a transverse resonance condition for narrow slot coupled waveguiding systems. The resulting modal equation takes the form $\det(I - \Gamma S) = 0$, where I, Γ, and S are 4×4 matrices representing respectively the identity matrix, the reflection coefficient of an obliquely incident wave at the guide edges, and the slot scattering effect. The solution for S consists of formulating an integral equation for the unknown fields in the slot, simplifying the singular kernel by assuming that the slot width $2g$ is electrically small, that is $2k_0g \ll 1$, and then solving the approximate integral equation. The form of S depends on whether the vertical electric field is evenly or oddly distributed about the slot. The solution for Γ depends on the type of guide wall. For a metal wall the problem is trivial, however, the reflection at the edge of a microstrip can be analyzed using more difficult Wiener-Hopf techniques.

A UNIFIED APPROACH TO MODAL DISPERSION OF STRIPLINE STRUCTURES IN LAYERED MEDIA

Bing-Hope Liu
Electromagnetics Laboratory
Department of Electrical Engineering
University of Colorado
Boulder, Colorado 80309

A new analytical method for the rapid evaluation of modal dispersion for general stripline structures in layered media will be proposed, based on employing the spectral domain formulation and utilizing some functional properties of the physical quantities concerned. The fundamental mode(s) as well as all the higher-order modes are treated in a unified way.

Consider the general configuration shown in Fig. 1. On the one hand, the exact spectral domain (i.e., Fourier transform domain) equations relating the tangential electric fields and the surface currents in the plane of strips ($y=0$ plane) is formulated. On the other hand, from the Fourier-transformed continuity equation

$$-j\beta\,\hat{I}_z(p) + jp\,\hat{I}_x(p) = -j\omega\hat{\sigma}(p)$$

a simple functional relation between the Fourier-transformed currents $\hat{I}_z(p)$ and $\hat{I}_x(p)$ is introduced:

$$p\hat{I}_x(p) = \xi(p,\beta)\cdot[-\beta\hat{I}_z(p)]\ . \qquad (*)$$

(Here p is the Fourier variable; the propagation factor $\exp(j\omega t - j\beta z)$ is understood and suppressed.) By combining (*) with the spectral domain equations, modal equation in terms of $\hat{I}_z(p)$ can be constructed which is relatively simple in mathematical setup. As an application example of the proposed method, the specific case of two-layered stripline structures will be discussed in detail. A waveguide-like interpretation of the modal equation will be pointed out.

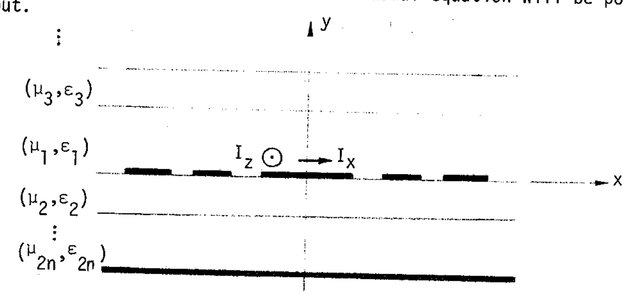


Fig. 1.

RADIATION FROM A BENT, NARROW MICROSTRIP ABOVE A GROUNDED DIELECTRIC SLAB

R.L. Holland and E.F. Kuester
Electromagnetics Laboratory
Department of Electrical Engineering
University of Colorado
Boulder, Colorado 80309

This analytical investigation considers the physical configuration of an electrically narrow microstrip situated on top of a grounded dielectric substrate, a configuration suited to integrated millimeter wave component applications. The main objective of the investigation is to characterize the radiation loss from guided microstrip modes as the result of bending the microstrip into a circular arc in the plane of the substrate. In particular, the dependence of such radiation upon the radius of curvature R of the microstrip arc and the physical parameters of the dielectric substrate are of interest. An additional objective of this investigation is to specify the manner in which energy lost from the guided microstrip modes is divided between skywave radiation and surface wave modes in the dielectric substrate. The analytical approach consists of generating appropriate integral equations relating charge and current densities on the microstrip which, when solved in conjunction with an integral equation expressing the conservation of charge on the microstrip, yield analytical representations for the propagation constants of guided modes for the bent microstrip. The local formulation of the radiation condition is employed to modify the integral equations consistent with the assumption that $k_oR >> 1$ (k_o is the free-space phase factor).

Perturbation Analysis of Radiation from Periodically Corrugated Dielectric Layers: Oblique Guidance Case

S. T. Peng and M. J. Shiau

Polytechnic Institute of New York
Microwave Research Institute
Brooklyn, New York 11201

An exact analysis of the radiation from periodically corrugated dielectric layers has been previously reported by one of the authors for the general case of surface-wave incidence at an oblique angle. It was shown that in the general case of oblique incidence, three different types of couplings generally arise: (1) coupling among space harmonics due to the periodic variation of the dielectric corrugation, (2) coupling of modes at the two planar surfaces of the corrugated region, and (3) cross coupling between the fields of the two polarizations (TE and TM) due to the oblique incidence. The exact analysis takes into account the effects of all the three types of coupling; as a result, it is rather involved mathematically and has to rely on a large capacity computer.

We present here an alternative method, that of a perturbation analysis that yields simple closed-form solutions for the radiation characteristics of the periodic structures. More specifically, the radiation of the surface wave in the presence of the periodic corrugation is formulated in terms of the radiation from an equivalent distributed dipole source. That source is due to the interaction of the surface wave with the periodic corrugation which is taken as a perturbation on a uniform (unperturbed) multi-layer dielectric structure.

Such a method was originally developed for the special case of normal incidence, where the TE and TM polarized waves exist independently; many useful closed-form solutions were then obtained for the two polarizations separately. We have observed that the equivalent dipole source vector for the general case of oblique incidence may be decomposed into two orthogonal vectors, each responsible for the radiation of one polarized wave. Thus, the closed-form solutions previously obtained for the normal-incidence case can be simply employed for the oblique-incidence case, with only a slight modification of the TE and TM source amplitudes that account for the important effect of cross coupling between the two polarizations. For illustration, typical structures of practical interest have been investigated by the method of perturbation analysis and the results are found to agree very well with those obtained by the exact analysis. Therefore, the method of perturbation analysis is simple to use and powerful enough to account for all important physical effects, and the closed-form solutions are particularly useful for practical design considerations.

On the Analysis of Millimeter or Optical Dielectric Waveguide Integrated Circuits - The Finite Element Approach

C. Yeh, T. Mazilu and S. Dong
Electrical Engineering Department
University of California, Los Angeles
Los Angeles, CA 90024

A new powerful technique to analyze problems dealing with millimeter wave guiding structures (such as the dielectric integrate circuits or the strip-line circuits) as well as optical guiding structures (such as the arbitrarily shaped inhomogeneous fiber guide or the optical integrated circuits) has been perfected. Not only can we deal with single guided wave structure but also with coupled structures. This technique is based on the finite element method. Representative examples on practical millimeter wave IC structures as well as realistic optical fiber or IC structures that are of current interest will be discussed.

NON-ADDITIVITY OF WAVEGUIDE AND MATERIAL DISPERSION IN SINGLE-MODE STEP-INDEX OPTICAL FIBERS: EXACT ANALYSIS

Paulo S.M. Pires
Department of Electrical Engineering
Federal University of Rio Grande do Norte (UFRN)
59.000-Natal, RN
Brazil

David A. Rogers
Department of Electrical and Electronics Engineering
North Dakota State University
Fargo, North Dakota 58105

Pulse dispersion in step-index optical fibers has been analyzed by the assumption that the waveguide dispersion, D_w, and material dispersion, D_m, combine by addition to give the total dispersion, D_T. Such an approach is based on the weakly-guided condition or on asymptotic formulas that are obtained from that condition. Since dispersion limits the bandwidth of the optical fiber, an accurate study of its behaviour is very important. The bandwidth becomes maximum at the wavelength of zero dispersion.

We have developed a method (Pires et al, 1981 IMS Digest, pp. 86-88) for analysis of pulse dispersion in step-index optical fibers that is based on solutions of the exact characteristic equation for the HE_{11} mode. This method permits a greater precision in prediction of the ideal wavelength for use with a given single-mode step-index optical fiber.

In this work we extend the analysis performed previously and present some theoretical curves for waveguide dispersion and curves to demonstrate that the assumption of additivity is not correct. Our analysis predicts errors larger than those calculated using the weakly-guided condition (D. Marcuse, Applied Optics, 18:7, Sept. 1979, pp. 2930-2932).

SYNTHESIS OF SINGLE-MODE OPTICAL FIBERS AT MINIMUM TOTAL DISPERSION WAVELENGTH

Paulo S.M. Pires
Department of Electrical Engineering
Federal University of Rio Grande do Norte
59.000 Natal, RN, BRAZIL

David A. Rogers
Dept. of Elec. and Electronics Engineering
North Dakota State University
Fargo ND, 58.102, USA

The core radius of single-mode step-index optical fibers is found at any desired wavelength assumed as the wavelength of minimum total dispersion, using an asymptotic approximation for the eigenvalue U (M. Miyagi and S. Nishida, JOSA, Vol.69, No.2, pp.291-293, 1979). This calculation, which was performed in a programable pocket calculator, permits the predetermination, with reasonable precision, of the ideal optical fiber that should be used with the optical source available.

CIRCULAR WAVEGUIDE BIFURCATION WITH INCIDENT TE_{11} AND TM_{11} MODES

H. Schilling and R. E. Collin
Electrical Engineering and Applied Physics Department
Case Institute of Technology
Cleveland, Ohio 44106

The bifurcated circular waveguide with an incident TE_{11} mode is a basic structure for dual mode coaxial primary focus antenna feeds. An exact solution to this bifurcation problem using the residue calculus method of solving a set of four infinite equations has been found. The problem differs from that for circularly symmetric incident modes for which published results exist. The main difference is that four, instead of two, infinite equations must be solved simultaneously and that in two of the equations an extra term that accounts for TE_{1n} and TM_{1m} mode coupling occurs. It is shown that this extra term can also be recovered as a contour integral residue contribution and thus enables the solution to the problem to be obtained using the residue calculus method. The theory as well as numerical results for the scattering matrix parameters of the junction will be presented.

MODE REFLECTION AT THE TRUNCATION OF A CONICAL HORN

V.Daniele, M.Orefice, R.Zich
CESPA - Centro Studi Propagazione e Antenne del CNR, Istituto di Elettronica e Telecomunicazioni, Politecnico di Torino, Italy

Very little attention has been paid in the past to the problem of the reflection at the truncation of a conical horn of arbitrarily wide flare angle. Although some recent works allow the evaluation of the reflection coefficient from the knowledge of the radiated field from truncated waveguides, they cannot be easily extended to non-uniform structures as conical waveguides.

In this work the problem is approached rigorously, by considering the canonical problem whose geometry is indicated in fig. 1, which can be reduced to a bi-dimensional problem because of the axial symmetry. There are some analogies with the bifurcated planar waveguide, with more complexity because here, in general, incident E(H) modes excite in the discontinuity also H(E) modes.

The problem is solved via modal matching, by introducing the conical-spherical modes in the three regions A,B and C, and obtaining a system of infinite equations in infinite unknowns. Due to some properties of the associated Legendre functions, the elements of the matrix can be evaluated explicitly, although some numerical problems may arise, in connection with the description of the conical modes.

In analogy with the case of the bifurcated waveguide, problems of relative convergence also arise, which are overcomed by the method proposed in the literature; moreover, the spurious modes excited can be taken into account with the considerations already developed for the truncated circular waveguide, which has been solved exactly.

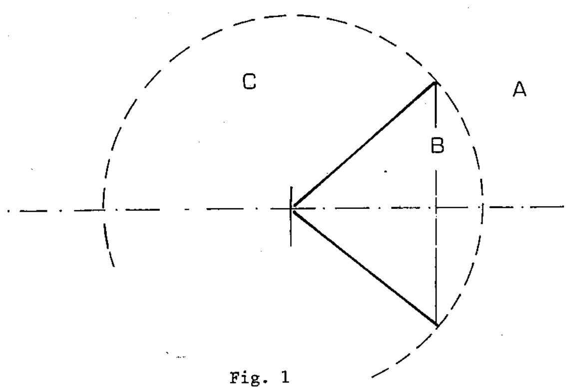


Fig. 1

A finite element method for the analysis of arbitrary volume of transition linking waveguides

J. AUDET - G. VANDERBORCK
THOMSON-CSF/DIS
104, Rue Castagnary
75015 PARIS - FRANCE

Today the microwave devices work with frequencies which increase more and more, so the sizes become very small. Both the technical engineering difficulties and the need to realize sophistic devices lead to consider structures with complex shapes. Then we cannot use simple analytical knowledges on geometries such that circles and rectangles for example. Our aim is to present a numerical technique which enables us to characterize any transitions between metallic waveguides.

The previous work of C.H. CHEN and C.D. LIEN (IEEE trans.MTT, Vol 28, N°6, Aug. 1980) leads us to apply a three dimensionnal finite element method in the transition volume. After a minimization principle applied to the variational formulation of the Helmoltz equation, we find a numerical representation of the electric field.

The computer program has been tested in a case where analytical result exists. We obtained good agreement with theory and now we are able to deal with complex geometries.

FFT, GTD AND GAD

S. W. Lee, R. Mittra and P. Ransom
University of Illinois
Urbana, Illinois

It is well-known that the scheme for Fast Fourier transform (FFT) was first published by Cooley and Tukey in 1965. But few people are aware of the fact that a similar scheme was invented by Professor G. A. Deschamps in the early 1950's. In fact, a part of his scheme was published on pp. 1009-1011 of ITT's book, "Reference Data for Radio Engineers" (4th Edition, 1959). In this short talk, we will discuss this and other contributions of Professor Deschamps.

ON THE EQUIVALENCE BETWEEN RAYS AND MODES

by

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

Source-excited high-frequency propagation in a ducting environment can be represented alternatively in terms of ray fields or in terms of guided (normal and leaky) modes. Although rays and guided modes express, respectively, a local and global description of the propagation process, there exists a quantitative relation between a group of modes and a corresponding group of rays. In essence, an angular spectrum interval of plane waves can be filled either with rays or with modal congruences whose trajectories lie within the interval, with "collective" ray or mode remainders accounting for any voids near the spectrum boundaries. The equivalence is established either by alternative asymptotic treatments of the truncated plane wave spectral integral, or directly by Poisson summation of a group of modes and a group of rays. The equivalence can be applied to generate hybrid ray-mode formulations that improve the rapidity of convergence of either a ray series or a mode series, and avoid troublesome ray or mode intervals by filling these with modes and rays, respectively. Numerical examples are provided for large inhomogeneously filled waveguides wherein ray fields undergo transitions near caustics and near the trajectories of critically reflected or glancing rays. Alternative treatment of the collective ray or mode remainders for these transition regions exhibits the utility of the various hybrid forms.

SLOPE DIFFRACTION FOR CONVEX SURFACES AND WEDGES

T. Veruttipong, R.G, Kouyoumjian, and P.H. Pathak
The Ohio State University, Department of Electrical Engineering
2015 Neil Avenue, Columbus, Ohio 43210

In this paper the uniform GTD (UTD) expressions for the fields diffracted by perfectly-conducting convex surfaces (P.H. Pathak et al, IEEE Trans., AP-28, 631-642, 1980) and wedges (R.G. Kouyoumjian and P.H. Pathak, Proc. IEEE, 62 1448-1461, 1974) are generalized to the case where the illuminating field at the point of incidence has a rapid spatial variation, so that the ordinary UTD must be augmented by slope-diffraction contributions.

Expressions for the UTD slope-diffracted fields for the convex cylinder case are obtained from the solutions to the two-dimensional (2-D) canonical problem of a circular cylinder illuminated by electric and magnetic line dipole sources. These 2-D solutions are then systematically extended to the 3-D problem of a circular cylinder illuminated by infinitesimal electric and magnetic dipoles. The generalization of the canonical circular cylinder results to treat the convex cylinder case has been achieved via the GTD procedure; a similar generalization to the arbitrary convex surface is currently being pursued.

Expressions for the slope-diffracted field of a wedge have been given by Hwang and Kouyoumjian (URSI 1974 Annual Meeting, Boulder, Colorado). The higher-order terms are derived here by asymptotically evaluating a plane-wave spectral representation of the diffracted field. These terms are also obtained by an alternative spectral method using discrete, inhomogenous plane waves. Both solutions can be interpreted ray-optically so that the slope-diffraction coefficient and the higher-order slope diffraction coefficients are obtained.

Numerical results are presented which demonstrate the importance of the slope diffraction contributions for cylinders and wedges; these are compared with numerical results obtained by other methods.

ON THE ACCURACY OF SOME EXTENSIONS OF THE UNIFORM GTD

R.Tiberio and G.Pelosi
Istituto di Elettronica
University of Florence
Florence, Italy

In the last few years some extensions of the uniform GTD (UTD) have been proposed in order to improve the versatility of this ray method so that it can be applied to a wider class of problems.

Recently uniform, closed form expressions for the diffraction by a wedge illuminated by a dipole close to its edge have been presented to significantly reduce the distance between the source and the edge. By introducing a ray fixed coordinate system and taking into account transverse and radial components of the incident field, the diffraction coefficient for the far-zone field due to an arbitrary directed dipole is expressed in terms of a 2x3 matrix. Calculations of the diffracted field for various locations and orientations of the dipole are now compared with numerical results based on an eigenfunction solution. It is found that the accuracy is excellent. In particular, for the radial component of the incident field the improvement is still significant for a distance between the source and the edge as small as 0.1λ .

In analysing the diffraction by an impedence strip both in free space and in an impedence ground plane, an asymptotic approximation analogous to that imployed in obtaininig the UTD, has been applied to the exact solution given by Maliuzhinets. A spectral, extended ray method has been used to calculate higher order, but yet significant diffracted fields. This approach is similar to that used in analysing the diffraction at edges in a perfectly conducting surface, illuminated by transition region fields. Calculations in several examples which involve perfectly conducting surfaces have demostrated the effectiveness of this method. Numerical results for the configurations mentioned above with arbitrary surface impedences, are shown and compared with those calculated from a moment method solution. Surface wave contributions are also included, and a very good agreement is found among the results obtained by the two different techniques.

ANOMALOUS ABSORPTION EFFECTS FOR BEAMS INCIDENT ON LOSSY LAYERED STRUCTURES*

V. Shah and T. Tamir
Department of Electrical Engineering and Computer Science
Polytechnic Institute of New York, Brooklyn, N.Y. 11201

Recent studies have shown that an anomalous absorption phenomenon occurs when a plane wave is incident under critical conditions on planar multilayered structures (V. Shah and T. Tamir, Optics Commun. 37, 383, 1981). The anomaly manifests itself in that very high and possibly total absorption of the incident energy occurs at structures whose intrinsic loss parameters are so small that only negligible absorption would be expected. This phenomenon has been verified experimentally (A. Amittay et al, Appl. Phys. Lett. 38, 754, 1981) and the high absorption effect has been explained in terms of a strong interaction between the incident wave and a leaky wave that may be supported by the structure.

The present work considers the anomalous absorption effect when the incident field is a realistic bounded beam rather than a plane wave of infinite extent. In addition to this effect, the reflected fields then exhibit a large lateral beam shift and a considerable amount of profile distortion. As these aspects have already been studied in the context of lossless configurations (T. Tamir and H.L. Bertoni, J. Opt. Soc. Amer. 61, 1397, 1971), the lossy situation considered here represents a generalization of those previous results. In particular, we find that an anomalous beam displacement can occur in the backward direction in contrast to the lossless case in which the displacement appears in the forward direction only.

The analysis of the generalized beam-displacement effect is carried out by assuming a Gaussian beam incident on a multilayered structure, which is characterized by a suitable plane-wave reflectance function $\rho(k_x)$, where $k_x = k \sin\theta$ denotes the (generally complex) wavenumber along the longitudinal direction of the layered configuration. Under the conditions that satisfy the anomalous absorption effect, i.e., when strong coupling occurs between the incident beam and a leaky wave that could be supported by the structure, $\rho(k_x)$ can be well approximated by $\rho(k_x) = R(k_x-k_o)/(k_x-k_p)$, where R is a constant, k_p is the complex wavenumber of the pertinent leaky wave and k_o is a complex zero of $\rho(k_x)$; with this expression, the scattered fields can be found in a closed form involving complex error functions of k_p and k_o. When viewed as functions of a specific loss parameter δ, both k_o and k_p vary with δ and, in particular, the structure exhibits a total absorption behavior at some critical value δ_c of δ. It then turns out that the lateral shift of the reflected beam is forward or backward depending on whether δ is smaller or greater than δ_c, respectively.

In addition to the systematic results that it yields, the above approach is convenient because it affords an analysis in terms of poles and zeros of the reflectance $\rho(k_x)$, which is a well known function for certain canonical configurations. The anomalously high absorption effect and its attendant lateral beam shift phenomenon is of interest to a number of applications; these include filters (in either the angular or frequency domains), non-destructive testing of thin-layer configurations, selective couplers for integrated optics, and others.

* This work has been supported by the National Science Foundation and by the Joint Services Electronics Program.

HIGH FREQUENCY PROPAGATION IN THE PRESENCE OF A CURVED DIELECTRIC INTERFACE

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

A high-frequency line source in a dielectric medium that is separated by a concave cylindrical boundary from an exterior medium with lower dielectric constant generates a variety of wave phenomena which have been explored extensively [B.Rulf, J.Math. Phys..8,1785-1793, 1967, D.S.Jones, Proc.R.S.E.(A),8,1-21, 1978]. This problem is re-examined here with a view toward clarifying relevant reflection and transmission characteristics within the framework of ray optics. Particular attention is given to the frequently employed "tunneling hypothesis", which assumes that the transmitted field due to a totally reflected incident ray is due to initial evanescent decay and subsequent radiation along a ray from a virtual caustic to the observer. The analysis proceeds from a rigorously formulated Green's function that is evaluated asymptotically in the high-frequency limit. The exterior domain is divided into illuminated and shadow regions separated by the transmitted tangent ray launched by a ray incident at the critical angle. Conventional ray optics is valid far from the tangent ray shadow boundary on the illuminated side. The shadow boundary is surrounded by transition regions wherein Fock type integrals, and Weber functions yielding local lateral waves, provide alternative representations. On the shadow side, not too far from the shadow boundary, the field can indeed be interpreted also via the tunneling hypothesis. However, deeper inside the shadow, the tunneling hypothesis is inapplicable, and the field is expressed either in terms of the Fock integrals or a residue series. Thus, the tunneling ray furnishes a valid phenomenological description only in the weak shadow but fails in the dark shadow zone. These conclusions have basic consequences for predicting the field and energy flow when the excitation is from a well-collimated beam.

EXACT STATIC AND DYNAMIC SOLUTIONS FOR TRUNCATED METALLIC CONES

V.G. Daniele
Politecnico di Torino, Italy

and

P.L.E. Uslenghi
University of Illinois at Chicago

A metallic circular cone of semiaperture angle $\theta = \theta_0$ truncated by a sphere at a radial distance $r = a$ from the tip is considered. Initially we examine the static problem of an arbitrary distribution of electric charges located on the symmetry axis. Laplace's equation for the potential is subjected to a change of variable for the radial coordinate, followed by a Fourier transform (the two steps are equivalent to using a Mellin transform). The solution in the transform domain is reduced to a modified Wiener-Hopf equation of the type: $A(\alpha)\ F_+(\alpha) + B(\alpha)\ F_+(-\alpha) = F_-(\alpha) + C(\alpha)$, where A, B and C are known, meromorphic functions involving Legendre functions of complex order.

The solution of the above equation is discussed, and particular cases are considered. When $\theta_0 = \pi/2$, the hemisphere is obtained. If the spherical truncation is absent, i.e., we have a thin conical shell of radial extent $r = a$, then $B = 0$ and we obtain previous results by Karp; in particular, $\theta_0 = \pi/2$ corresponds to the circular disk.

The extension of our exact results for the static case to the dynamic case is discussed; its possibility hinges on properties of the Kantorovich-Lebedev transform.

On the Eigenfunction Expansion of Electromagnetic Dyadic Green's Functions

P.H. Pathak
The Ohio State University ElectroScience Laboraotry
1320 Kinnear Rd., Columbus, Ohio 43212

A relatively simple method is presented for obtaining the complete eigenfunction expansion of the electric and magnetic fields, $\overline{E}$ and $\overline{H}$, respectively, which are produced by a time harmonic electric point current source that may radiate in the presence of boundaries. As a result of the point source excitation, this expansion of $\overline{E}$ and $\overline{H}$ automatically yields the complete eigenfunction expansion of the corresponding electric and magnetic dyadic Green's functions, $\bar{\bar{G}}_e$ and $\bar{\bar{G}}_m$, respectively. As a first step in this method, the $\overline{E}$ field which is valid everyplace outside the source point is constructed in terms of only the solenoidal eigenfunctions via well known techniques. This solenoidal expansion denoted by $\overline{E}'$ also directly yields the complete eigenfunction expansion of $\overline{H}$, and hence of $\bar{\bar{G}}_m$. Next, it is shown in a general fashion that the delta function correction to $\overline{E}'$ which is necessary for obtaining the complete eigenfunction expansion of $\overline{E}$ or $\bar{\bar{G}}_e$ (that remains valid at the source point) is directly available from the relation governing the discontinuity in $\overline{H}$ across the source point, without having to know $\overline{H}$ (and $\overline{E}'$) explicitly, if one employs an elementary result from distribution theory. Applications of this procedure are illustrated by finding $\bar{\bar{G}}_e$ and $\bar{\bar{G}}_m$ for some typical interior (waveguide and cavity) and exterior electromagnetic problems.

ON THE COMPUTATION OF DYADIC GREEN'S FUNCTIONS IN TERMS OF CYLINDRICAL VECTOR WAVE FUNCTIONS

L. Wilson Pearson
Department of Electrical Engineering
University of Mississippi
University, MS 38677

The vector wave function wxpansion method provides an elegant formal approach to the construction of dyadic Green's functions in electromagnetics as Tai indicates in his pioneering work (*Dyadic Green's Functions...*, Intext, 1971). The resulting expansions are not directly amenable to efficient numerical computation because they involve three-dimensional spectral summations which often converge slowly. In the cylindrical coordinate expansion, treated here, a discrete sum in the azimuthal spectral index is involved along with integrations over radial and longitudinal wavenumbers. As Tai indicates, the radial wavenumber integration may be manipulated so that it admits to analytical integration by way of the calculus of residues.

In this presentation we consider the computational implications of the longitudinal wavenumber integration which remains. The algebraic convergence of this integral is improved upon by first separating out the singular components of the sum in order to leave a remainder integrand which admits an application of Jordan's Lemma. This leads to the deformation of the original integration path into a new path along the branch cut intrinsic to the formulation. The integrand decays exponentially asymptotically along this path, thereby offering a computationally-appealing form. The boundedness of the integrand near the branch point is considered carefully and is shown to hinge on the inclusion of an electrostatic term resulting from the radial wavenumber integral—a term which apparently has not been accounted for in earlier work. Collin recently pointed out a similar term in the spherical wavefunction expansion (XX URSI General Assembly, Washington, D.C., Aug. 1981).

OBSERVATIONS RESULTING FROM EIGENSOLUTIONS OF INTEGRAL EQUATIONS

D. R. Wilton
C. M. Butler
Department of Electrical Engineering
University of Mississippi
University, MS 38677

Electrostatic and electromagnetic boundary-value problems are generally solved by either one of two procedures: 1) If the geometry is separable, the fields are expanded in wavefunctions appropriate to the geometry and the solution is obtained by enforcing conditions at boundary surfaces, or 2) if the geometry is non-separable, an integral equation for the unknown boundary fields or equivalent sources is formulated and solved numerically. It is less well-known that separable problems often can be formulated as integral equations and solved analytically. All that is required is the existence of an addition theorem by means of which the kernel of the integral equation may be expanded in terms of wavefunctions appropriate to the separable geometry.

We have found that the analytical solution of boundary-value problems by integral equation methods provides considerable insight into the properties of integral operators—and in one case yields an unexpectedly simple form of the solution to a classical electrostatics problem. Such properties investigated include the role of constraint conditions in integro-differential equations; the boundedness or unboundedness of several types of integral operators; the non-uniqueness problem, or equivalently, the internal resonance phenomenon associated with certain integral equations; the form and roles of various terms in singularity expansion representations of surface currents. In addition, a number of practical quasi-static problems have been solved analytically by integral equation methods.

The procedure for analytically solving of an integral equation is illustrated for a number of examples. Some interesting features are pointed out for each example.

Separable kernels $\Rightarrow$ Resolvent Kernel for solution

VARIATIONAL METHODS FOR NONSTANDARD EIGENVALUE PROBLEMS IN ELECTROMAGNETICS

I.V.Lindell
Helsinki University of Technology
Radio Laboratory, Otakaari 5A
02150 Espoo, Finland

The nonstandard eigenvalue problem is defined by the general operator equations $L(\lambda)f=0$, $B(\lambda)f=0$, where L and B are linear operators (e.g., differential operator and boundary condition operator) and may possess any functional relation on the parameter λ. In standard eigenvalue problems L is a linear function on λ and B does not depend on λ at all. It is shown that many important problems in electromagnetics can only be formulated in nonstandard form and that there exist problems which can be formulated both in standard and in nonstandard form, of which the nonstandard formulation may lead to a simpler solution of the problem.

A unified variational principle is presented, from which a functional equation for the nonstandard eigenvalue can be obtained for self-adjoint operators L,B (e.g., lossless or reciprocal problems). From this, a stationary functional for the interesting parameter can be found in some cases in explicit form. If the problem has many parameters, the problem may be solvable through one of the parameters, for which an explicit variational functional exists.

Several examples are considered and the principle is tested. The nonstandard eigenvalue may be any physical parameter involved in the problem. In the examples we consider the surface reactance of a waveguide in cutoff, the propagation factor of an azimuthally magnetized ferrite-filled waveguide, the magnetization in the same problem, the depth of corrugations in a corrugated waveguide at cutoff, the dielectric constant of an insert in a resonator and the geometrical measure of the dielectric insert.

RADIATION PROPERTIES OF A TE_{11}-TM_{11} DUAL MODE COAXIAL WAVEGUIDE

R. E. Collin and H. Schilling
Electrical Engineering and Applied Physics Department
Case Institute of Technology
Cleveland, Ohio 44106

An exact solution for the field radiated from the coaxial circular waveguide shown in Figure 1 has been found. The TE_{11} and TM_{11} mode amplitudes of the incident waves at the aperture are found using exact solutions for the scattering matrix parameters of the two junctions. The radiated field was found using the Weiner-Hopf method.

The optimum dimensions of the radiator have been determined so as to produce a circularly symmetric radiation pattern with a minimum of cross-polarization. Cross-polarization 50 dB. or more below the co-polarized field is predicted. The sensitivity of the cross-polarization level with parameter variations and change in frequency has also been determined. It was found that the cross-polarization will remain below -30 dB. over a 4 to 5% bandwidth.

Both theoretical and experimental results for co- and cross-polarized radiation patterns will be presented as well as typical solutions for optimum dimensions and cross-polarization levels.

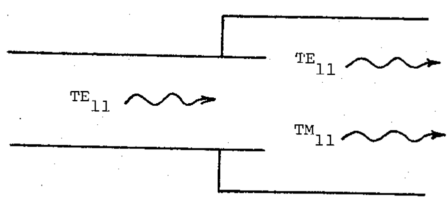


Figure 1 - Circular Coaxial Waveguide Radiator

APPROXIMATION OF FACTORIZED WIENER-HOPF KERNELS

Lawrence W. Rispin
Electromagnetics Laboratory
Department of Electrical Engineering
University of Colorado
Boulder, Colorado 80309

The Wiener-Hopf technique finds a great deal of use in open region electromagnetic field theory problems having semi-infinite geometries, Common to such analyses is the factorization of an even ($F(-\alpha) = F(+\alpha)$) Wiener-Hopf kernel into two symmetrical factors ($F(\alpha) = F_+(\alpha)\ F_-(\alpha)$ where $F_+(-\alpha) = F_-(+\alpha)$) which are analytic and free of zeroes in overlapping half-planes in the transform domain. Although compact formal expressions can be written for the factors, $F_+(\alpha)$ and $F_-(\alpha)$, more useful practical expressions (Bates and Mittra, IEEE Trans. Ant. Prop., AP-17) usually require a substantial amount of numerical processing. However, approximate analytical formulas for these factors can be constructed for values of the transform variable α within the visible portion of the real axis, i.e., $-k \leq \alpha \leq +k$, where $k = 2\pi/\lambda$ and λ is the operating wavelength. These approximate formulas are based upon a Taylor series expansion of an appropriate form of the desired "plus" (or "minus") factor about the point $\alpha = 0$. By removing any identifiable behaviors of the "plus" factor prior to expansion, the resulting Taylor's series can be truncated after a few important terms. The coefficients of these terms are dependent only upon electrical parameters and may be numerically evaluated or approximated. The approximation of a "plus" factor, $F(\alpha)$, via a truncated Taylor series in this manner, does not introduce a significant amount of error but does greatly reduce the computational effort.

Specific examples are given for the "plus" factors of the Wiener-Hopf kernels,

$$K_m(\alpha) = i\pi J_m(a\sqrt{k^2 - \alpha^2})\ H_m^{(1)}(a\sqrt{k^2 - \alpha^2}) \quad \text{and}$$

$$L_m(\alpha) = i\pi J_m'(a\sqrt{k^2 - \alpha^2})\ H_m^{(1)\prime}(a\sqrt{k^2 - \alpha^2})$$

where J_m and $H_m^{(1)}$ are the Bessel and Hankel functions, respectively, of the first kind and "$'$" indicates differentiation with respect to the argument. These Wiener-Hopf kernels occur in cylindrical antenna theory as well as acoustic or open-cylindrical waveguide radiation problems.

A STUDY OF THE REDISTRIBUTION OF THE CURRENT AT THE

END OF A HOLLOW TUBULAR CYLINDER

David C. Chang and Lawrence W. Rispin
Electromagnetics Laboratory
Department of Electrical Engineering
University of Colorado
Boulder, Colorado 80309

Although not very well known, the solutions for the (azimuthally-directed as well as axially-directed) current densities on a semi-infinite tubular cylinder illuminated by a uniform plane wave are available from a general Wiener-Hopf analysis (J.D. Pearson, Proc. Camb. Phil. Soc., 49, 659-667 and J.J. Bowman, Internal Memorandums, Conductron Corp., Ann Arbor, Mich.). However, due to their complexity, little has been done with regard to using these solutions to explain the redistribution of the currents at a cylinder end. The general Wiener-Hopf solution is re-examined and "primary" and "reflected" current densities are designated in a "cause and effect" type of formulation, which also makes use of the association of these current densities with either Transverse Electric (TE to the cylinder axis) or Transverse Magnetic (TM to the cylinder axis) field distributions. In this manner, the coupling between the azimuthally-directed and axially-directed current densities is understood in terms of the interdependencies of the TE and TM field distributions at the cylinder end which are brought about by the physical behaviors (the so-called "edge conditions") demanded of the total field near this cylindrical edge. The different attenuation rates of each mth order azimuthal variation of the reflected current densities explains the so-called "shadowing" of the backside of the cylinder.

Numerically evaluated data for the current densities on an electrically-thick ($ka = 1$) semi-infinite tubular cylinder is given to demonstrate and substantiate the concepts presented. For a cylinder of finite length, the use of travelling wave concepts yields an analytical expression for the current standing-wave pattern on a cylindrical dipole antenna even when the radius of the antenna is electrically thick. The advantage of this formulation over a totally numerically-oriented scheme (say, the moment method) is that we can isolate a problem which is a function of three physical parameters (incident angle, length, radius) to one involving only two, i.e., incident angle and radius, while keeping the length dependence explicitly determined. This allows us the opportunity to develop analytical approximation and/or universal curves for antennas of arbitrary length.

INTEGRAL EQUATION FOR SCATTERING BY A DIELECTRIC BODY

Egon Marx
National Bureau of Standards
Washington, DC 20234

We consider the scattering of a transient electromagnetic wave in free space by a uniform dielectric body. We show how the scattered and transmitted fields can be obtained from a single tangential vector field on the surface of the dielectric, as is the case for scattering by a perfect conductor.

We first express the electric and magnetic fields in a region in terms of the sources, the initial values of the fields in the region, and the fields in the surface. We then express the incident fields in terms of the initial values and relate the normal components of the field on the surface to the tangential components. We define two pairs of auxiliary fields that obey a single set of Maxwell equations in both regions. The first fields are equal to the scattered fields in free space and obey the free-space Maxwell equations in the body, the tangential component of the electric field is continuous, and the jump of the tangential component of the magnetic field across the surface is our one unknown field. The second fields are equal to the transmitted fields in the body and they vanish outside. The boundary conditions on the physical fields allow us to determine the jumps of the second pair of auxiliary fields in terms of the unknown tangential field. The fields on the surface are defined in terms of the so-called principal value integrals over the surface, and they are equal to the average of the limits of the fields inside and outside the body. We derive a singular integral equation of the first kind for the unknown field.

We finally show why the fields so obtained are the solution of the initial problem. A rigorous proof can be formulated in terms of distributions.

This approach is similar to the one developed originally for the scattering of monochromatic plane waves by an infinite periodic grating (D. Maystre, in Electromagnetic Theory of Gratings, edited by R. Petit, Springer, Berlin, 1980, pp 63-81). We have also applied this formulation to the three-dimensional scattering of monochromatic waves.

This derivation parallels the rigorous theory based on the theory of distributions. In numerical calculations, we can expect a reduction of the storage requirements to one-half that needed for the usual formulation in terms of two tangential fields.

SUBHARMONIC AND SUPERHARMONIC BRAGG RESONANCES
IN ALMOST PERIODIC MEDIA

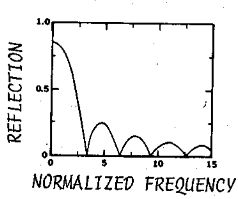
D.L. Jaggard† and J.M. Abel*

†Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Penna. 19104

*Department of Mechanical Engineering and Applied Mechanics
University of Pennsylvania
Philadelphia, Penna. 19104

Although the theory of almost periodic functions has been known since the work of early twentieth century mathematicians, many of the applications of this theory to problems in applied physics and engineering have been more recent [see e.g., A.R. Mickelson and D.L. Jaggard, IEEE Trans. Ant. Prop. AP-27, 34-40 (1979); D.L. Jaggard and A.R. Mickelson, Appl. Phys. 19, 405-412 (1979); or D.L. Jaggard and G.T. Warhola, Radio Sci. 16, 467-473 and 475-479 (1981)]. Here we investigate subharmonic and superharmonic effects in media with multiple periodicities. These effects are the analogues of combination resonances observed in the initial value context [J.M. Abel, Quart. Appl. Math. 28, 205-217 (1970)]. The resonances are of interest in distributed feedback structures or couplers for use in optical and microwave integrated circuits and in naturally occurring phenomena where several periodicities are present and contribute to the scattering or reflection of waves.

To exemplify these phenomena, we consider the reflection of waves from unbounded structures with almost periodic permittivities. The presence of these subharmonic and superharmonic Bragg resonances can be seen immediately from momentum conservation or phase matching diagrams [D.L. Jaggard and J.M. Abel, Proc. IEEE 69, 1510-1511 (1981)] while the details of these effects can be shown by use of coupled mode equations. The results indicate that large reflections can occur not only at the fundamental Bragg frequencies, but also at the sum and difference Bragg frequencies. These subharmonic and superharmonic Bragg reflections can be completely characterized by the theory developed here. An example of subharmonic reflection is shown in the reflection coefficient plot below. Note that the reflection coefficient approaches unity.



The absolute value of reflection is shown as a function of normalized frequency in the vicinity of subharmonic resonance for a structure characterized by a permittivity with two wavenumbers.

PULSE PROPAGATION THROUGH RANDOM OCEAN BOTTOM SEDIMENTS:

I. M. Besieris and W. E. Kohler
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

A study has been initiated of bottom-scattered pulsed acoustic signals, with the ultimate objective of providing a realistic theoretical model for available Hatteras abyssal plain data. This study is being carried out using a generalized two-frequency radiative transfer equation [I. M. Besieris and W. E. Kohler, "Two-Frequency Radiative Transfer Equation for a Statistically Inhomogeneous and Anisotropic Absorptive Medium," in Multiple Scattering and Waves in Random Media, edited by P. L. Chow, W. E. Kohler, and G. C. Papanicolaou (North-Holland Publishing Co., New York, N. Y. 1981)].

The two-frequency radiative transfer equation has been examined in detail in the special case of lossy ocean bottom sediments exhibiting highly anisotropic "pancake-like" statistical fluctuations, in addition to refracting density and sound speed profiles. Under these conditions, and for plane pulsed wave incidence, the transport equation for the incoherent mean intensity can be reduced to a "local" Schuster equation description which can be examined via a WKB analysis, albeit in a nontrivial manner.

The sediment density and sound speed random fluctuations define a renormalized (or effective) medium in which the rays associated with the mean field penetrate more deeply than those in the absence of randomness. Moreover, the effect of the random "pancake" medium becomes most pronounced as the rays near the turning points, i.e., as the rays tend to flatten out and run parallel to the random "pancakes".

It is our intent in this exposition to present a WKB analysis of the transport equation and compare the results of our theoretical model with existing data. We shall also discuss the relevance of our approach to physically important problems arising in the area of electromagnetic random wave propagation.

GENERATION OF WIDE BANDWIDTH SIGNALS AFTER PROPAGATION THROUGH RANDOM MEDIA

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

An analytical/numerical technique is described to generate realizations of the received signal after propagation of a wide bandwidth waveform through a layer of strongly turbulent media. These signal realizations are generated to have Rayleigh amplitude statistics (Fante, IEEE Trans. Antenna Propaga., AP-23, pp. 382-385, May 1975) and to have spatial and frequency correlation properties which obey the parabolic wave equation in the strong scatter limit.

This technique is based upon the solution for the two-frequency mutual coherence function, Γ, for spherical wave propagation with transmitter and receiver located on opposite sides of a finite layer of ionized electron density irregularities. An analytic solution may be obtained for Γ in the strong scatter regime by use of the quadratic approximation for the phase structure function. The thin phase-screen approximation to the thick layer is then utilized and great simplification to the analytic expression for Γ is obtained. The relationship between the impulse response function of the propagation channel and the two-frequency mutual coherence function and its Fourier transform is then used to directly obtain statistical realizations of wide bandwidth signals.

The accuracy of the thin phase-screen approximation is discussed and several comparisons of statistical signals with signals obtained directly from a multiple phase-screen propagation calculation (Bogusch, et al., Proc. IEEE, 69, pp. 787-796, July 1981) are considered.

These statistical realizations may be used as direct input to digital receiver modems to represent the effect of propagation through an ionospheric environment disturbed by barium releases or other sources of enhanced ionization. Although these statistical signal realizations apply only to the case of strong scattering, their generation requires only a fraction of the computer resources required for signal generation by wide bandwidth multiple phase-screen calculations.

TRANSMISSION, BACKSCATTERING, AND DEPOLARIZATION OF WAVES IN RANDOMLY DISTRIBUTED SPHERICAL PARTICLES

Akira Ishimaru
Rudolf Lap-Tung Cheung
Department of Electrical Engineering
University of Washington, Seattle, WA 98195

This paper starts with the general formulation of the radiative transfer equation for a plane-parallel medium of spherical particles when an arbitrarily polarized plane wave is incident. General equation of transfer in terms of the Stokes' parameters is decomposed in Fourier components and the equation of transfer for each component is obtained. It is shown that when the incident wave is linearly polarized and is normally incident on the medium, only two Fourier components result. The copolarized and cross-polarized components of the diffuse specific intensity are calculated and they show sinusoidal variations with the azimuthal angle. The degree of polarization is also calculated for various directions and optical thickness. When the incident wave is circularly polarized, the coupling between (I_1,I_2) and (U,V) disappears. The equation of transfer is solved by the discrete-ordinates method with the eigenvalue-eigenvector technique. The size distribution of particles can be taken into account and the transmission and backscattering received power for various field-of-view is calculated. The calculations are made for optical waves at 0.5, 1, 5, 10, and 15 μm in fog and microwaves at 20, 30, and 60 GHz in rain. Some discussions are also given for non-spherical particles.

BACKSCATTERING FROM ANISOTROPIC RANDOM MEDIA

Stanford P. Yukon
Electromagnetic Sciences Division
Rome Air Development Center
Hanscom AFB, MA 01731

The cross section for backscattering from an anisotropic random dielectric medium is computed for the case where the wavelength is much smaller than the outer scale length of the medium and where the path length through the medium can be many times the mean free path for small angle forward scattering. The cross section σ as a function of θ_i and θ_f, the initial and final scattering angle with respect to the major axis of an assumed distribution function, is obtained by an extension of the cumulative forward scatter - single backscatter calculation of DeWolf (IEEE AP19, 254, 1971). The cross section for the general case is computed by expanding the summed Born series as a functional Taylor series of convolved correlation functions. The dependence of the computed cross section on θ_i and θ_f is exhibited in curves showing the deviation from specular reflection for various fixed θ_i and the dependence of $\sigma(\theta_i=\theta_f)$ on θ_i. The dependence of σ on different choices of major and minor axis scale lengths is also presented. Application of the theory to backscattering from striations along magnetic field lines in the ionosphere is discussed.

A more general formulation of the backscattering problem outlined above using the Taylor series convolution expansion in conjunction with a cumulant expansion of σ expressed as a functional integral is also presented.

RL 714

BACKSCATTER FROM A RANDOM MEDIUM

P. Jedrzejewski and C-M Chu
Radiation Laboratory
Department of Electrical and Computer Engineering
The University of Michigan
Ann Arbor, MI 48109

In the conventional parabolic approximation for wave propagation in a random medium only forward scattering is taken into account. In this work the effect of backscattering is considered. By resolving the field into a forward and a backward component using a Bremmer series representation a set of coupled parabolic equations result. Using the Furutsu-Novikov formulation assuming a Markov approximation extended to include backscatter, coupled equations for the first and second moments of the forward and backward propagating components are obtained. Solutions for the case of a plane wave normally incident to a parallel plane random slab are obtained. Results for the average fields are obtained analytically, while numerical schemes are employed to solve the second moment equations assuming Gaussian and exponential correlations for the dielectric constant. Some typical results illustrating the behavior of the average fields and coherence functions for varying permittivity fluctuations and slab thicknesses are presented.

A THEORETICAL COMPARISON BETWEEN TWO RAIN ATTENUATION PREDICTION METHODS FOR TERRESTRIAL PATHS

Emanoel Costa and Manoel G.S. Dias*
CETUC-PUC/RJ - Rua Marquês de S.Vicente 225
22453 Rio de Janeiro, BRASIL

Most of the papers comparing different rain attenuation prediction methods for terrestrial paths have approached this problem through the analysis of the results yielded by each method, assuming a common input. The most important limitation of this approach is located in its inability in providing an insight into the causes for the agreement (or disagreement) between the methods. Since it may not be feasible to run an exhaustive comparative test, it may be dangerous to extrapolate the results to untested situations.

Following a different approach, it is shown in this paper that the integral proposed by Misme and Fimbel[1] for the prediction of the rain attenuation distribution for a terrestrial path from the knowledge of the rain rate distribution in its neighborhood can, under some simplifying assumptions, be analytically evaluated. Although the final expression is relatively involved, it is shown that its leading term agrees exactly with the expression proposed by Assis and Einloft[2] to perform the same prediction. That is, the method proposed by the latter authors is, as they claimed in their paper, an approximate solution for the Misme and Fimbel integral and there is an intrinsic relationship between the two methods.

Finally, rain attenuation values have been calculated by each prediction method for the same percentage of time, assuming a large number of combinations of input parameters (frequencies, path lengths, and rain rate distributions), in order to quantitatively estimate the relative difference between the results yielded by them. A very good agreement between the methods has been found, especially considering the great simplicity of the one proposed by Assis and Einloft.

---

*On leave from Universidade Federal do Pará.

1. Misme, P., and J. Fimbel, Theoretical and Experimental Determination of Attenuation Due to Rain on a Radio Path, Ann. Télécom., 30(5-6), pgs. 149-158, (1975).

2. Assis, M.S., and C. M. Einloft, A Simple Method for Estimating Rain Attenuation Distribution, Ann. Télécom., 32(11-12), pgs. 478-480, (1977).

ELEVATION ANGLE DERIVATIVES OF IONOSPHERIC PATH LENGTHS

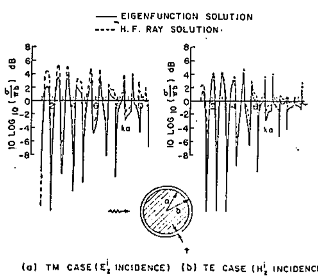
Saul Silven
GTE Products Corporation
Sylvania Systems Group-Western Division
Mountain View, California 94042

Integral expressions are derived for the derivatives of group path, phase path, and ground range with respect to ground elevation angle for propagation via a radially symmetric ionosphere. The integration singularity at the ray apogee point is circumvented by the careful selection of a change in the variable of integration. The resulting expressions imply two curious phenomena. First, when evaluated at zero elevation angle, all three derivatives are not only identical, but also independent of the ionospheric profile. This value is the negative of twice the earth radius. Second, as a corollary, the skip distance and Pedersen rays must always have an elevation angle greater than zero for a radially symmetric ionosphere.

ELECTROMAGNETIC SCATTERING FROM A CYLINDER COATED WITH A DIELECTRIC LAYER **

NAN WANG
THE OHIO STATE UNIVERSITY ELECTROSCIENCE LAB
DEPARTMENT OF ELECTRICAL ENGINEERING
COLUMBUS,OHIO 43212

An infinitely long, perfectly conducting, circular cylinder is coated with a dielectric material of uniform thickness. The high frequency scattering of incident plane electromagnetic waves from it is resolved into a geometrical optics ray and two surface waves similar to the fields scattered by a bare cylinder, except the former is modified by a reflection coefficient and the diffraction coefficients and the eigenvalues (the Regge poles) associated with the latter are alteared. For thick enough coatings the surface waves moving around the cylinder resemble those trapped in a planar, grounded, dieletric slab. It is found that the dominant surface waves have a small attenuation rate so that all the multiply-encircled waves must be taken into consideration in a self-consistent fashion. As a consequence, resonances appear in the scattering cross section. The surface wave interpretation of the resonance phenomenon and the condition for predicting the resonance frequencies are discussed. The normalized radar cross section of the coated cylinder obtained from the high frequency ray solution compares well with the eigenfunction result (see Figure below).



NORMALIZED RADAR CROSS SECTION OF AN INFINITELY-LONG, COATED, CIRCULAR CYLINDER (ϵ_r = 2.56, t = 0.41λ_0)

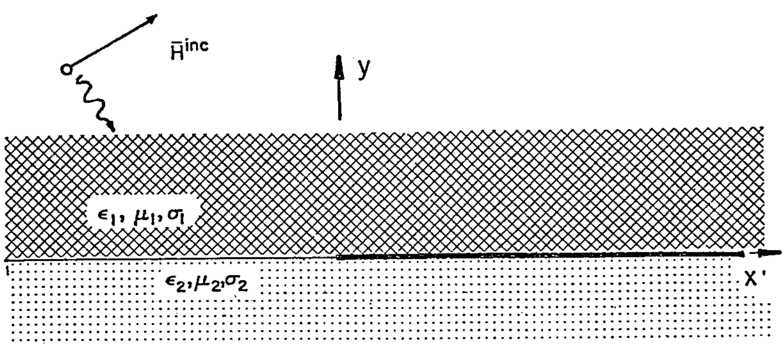
** Work supported in part by Department of Navy, Joint Service Electronics Program, Contract N00014-78-C-0049 with the Ohio State University Research Foundation.

DIFFRACTION BY A PERFECTLY-CONDUCTING HALF-PLANE ON A DIELECTRIC INTERFACE

R. Dawson Coblin
L. Wilson Pearson
Department of Electrical Engineering
University of Mississippi
University, MS 38677

The problem of electromagnetic diffraction by a perfectly-conducting half-plane residing on the interface between two semi-infinite media as shown in the figure below may be formulated as a Wiener-Hopf integral equation (P.C. Clemmow, *The Plane Wave Spectrum...*, Pergamon, 1966). While the problem has been formulated for some time, the factorization of the transform of the kernel of the integral equation has been an obstacle to its solution. A recent paper by Sunahara and Sekiguchi treats a related problem where the half plane stands a fixed distnace away from the interface (*Radio Sci.*, v. 16, no. 1, pp. 141-155) and another closely-related problem is treated in a paper by Heitman and van den Berg (*Can. Jour. Phys.*, v. 53, pp. 1305-1317).

This presentation reports the results of a study in which numerical techniques were used to carry out the factorization in the Wiener-Hopf formulation for the structure shown under TM plane-wave excitation. The form of the factorization integral is similar to that of Heitman and van den Berg, however the present approach alters the integral so as to form an efficient integral for numerical evaluation. Through analytical techniques the doubly infinite integral is altered to a rapidly-convergent finite definite integral valid for any medium parameters. Certain questions about the existence of the solution are examined. The asymptotic far field results of the Wiener-Hopf procedure are discussed and contributions of different components displayed.



ANALYTICAL SAMPLING AVOIDS AXIAL CAUSTICS IN GTD

E. H. Villaseca and R. W. Berchtold
Hughes Aircraft Company
Ground Systems Group
Fullerton, California

Geometrical Theory of Diffraction has proved to be a rapid and accurate technique for paraboloidal reflector antennas in calculating the total scattered field for all areas of the radiation pattern except at caustics. In order to circumvent these difficulties, the region around the axial caustic is sampled at the Nyquist rate. This rate is determined by the Wittaker-Shannon theorem which establishes a sampling rate from the dimension of the equivalent planar aperture enlarged so that it is coincident, within a prescribed approximation, with the field scattered by the reflector.

The GTD samples around the axial caustic are used to reproduce the radiation pattern through the caustic. Thus, the necessity of using non-GTD methods at the caustic is eliminated.

MACDONALD'S VS KELLER'S THEORY OF DIFFRACTION

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

In comparing the Macdonald and Keller theories of diffraction,D.S.Jones stated in his book:The Theory of Electromagnetism (Pergamon Press,Oxford,1964,p.651): '...the method advocated by Keller can be regarded as a physical version of Macdonald's theory...'. In view of the continued interest in Keller's Geometrical Theory of Diffraction, it may be appropriate to find the relation between the two theories.

The problem considered is the approximate high frequency evaluation of the far field scattering of electromagnetic waves by a smooth perfectly conducting body. Since Macdonald's work was written about 1917, the presentation intends to give the theory in a more compact form. The analysis is based on the asymptotic evaluation of the current surface integral. The use of the stationary phase method, approximates the far field in both the lit and shadow regions in terms of the local fields at certain diffraction points. This is compared with Keller's GTD. The concept of multiple diffraction as given by Macdonald is also investigated. The evaluation of the field at the caustics is also presented. Some possible extensions of the theory are discussed.

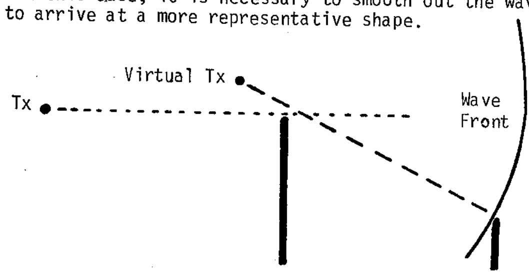
WAVE DIFFRACTION OVER SEVERAL OBSTRUCTIONS

J.H. Whitteker, Communications Research Centre, Department of Communications, Box 11490, Station "H", Ottawa, CANADA K2H 8S2

This paper describes a GTD calculation of the amplitude of a wave diffracted over a series of obstructions, assumed to be knife edges. The calculation is done to first order in λ/D, where D is the path length. In the case of two obstructions, it is possible to test the results against the complete Fresnel-theory calculation worked out by Millington et al. (Proc. Inst. Elect. Eng., C-109, 419-429, 1962). By this test, the first-order theory is much more accurate than the semi-empirical methods that are used in calculations done by hand. It should be possible to deal with many obstructions in series before an accumulation of small errors becomes serious. (The task of working out the complete Fresnel theory for more than two obstructions would be very laborious.)

Application of Huygens' principle to the diffraction problem involves integrating over the wave front above each obstruction. In the GTD method, one point on the wave front is chosen to represent the whole wave front, which is then assumed to have the same wave intensity and curvature everywhere. The point chosen is one that would dominate the integral if it were done exactly.

In order to visualize the calculation, it is useful to project the wave front backward to a virtual transmitter. This virtual transmitter turns out to be close to the crest of the preceding obstruction, if that obstruction is well above the line of sight. If the preceding obstruction is not well above the line of sight, the virtual transmitter lies above its crest, and closer to the real transmitter (see diagram). When the crest of an obstruction is below the line of sight, the wave front becomes corrugated, and a local value of the direction and curvature no longer represents the whole wave front very well. In this case, it is necessary to smooth out the wave front to arrive at a more representative shape.



DIFFRACTION BY ARBITRARY-ANGLED DIELECTRIC WEDGE:

Se-Yun Kim, Jung-Woong Ra, and Sang-Yung Shin
Korea Advanced Institute of Science and Technology
Seoul, Korea

A generalized asymptotic scheme for the calculation of fields scattered by a dielectric wedge of arbitrary angle is obtained when the incident plane wave is polarized parallel to the edge of the wedge. Scattered fields are obtained in terms of geometric optical contributions and the diffracted cylindrical wave emanating from the edge. An asymptotic correction to the physical optics approximation is derived to satisfy a dual series equation amenable to simple calculation, as in the case of the right angle dielectric wedge.

Joo, Ra, and Shin (Electronics Letters, Vol. 16, No. 24, pp. 934-935, 1980) showed for the right angle dielectric wedge that the scattered field may be obtained by a sum of the physical optics approximation and its edge correction field. It will be shown that the same method can be applied to obtain fields scattered by the arbitary angle dielectric wedge as follows: Physical optics solution which may be easily obtained yield geometric optical terms, such as reflected and refracted waves, and the edge diffracted field. The unknown correction field plus the physical optics solution is substituted into the dual integral equation in the spectral domain and a new dual integral equation for the equation for the correction field is derived. By representing the unknown correction field in multipole expansion, a dual series equation for the correction field is obtained and solved by a simple numerical method.

The simple numerical calculation provides the edge diffraced cylindrical wave pattern valid asymptotically, which exhibits vanishing behavior on the dielectric interfaces and approaches to that of the perfectly conducting wedge in the limit of large dielectric constnat. Reflected and refracted field terms accounting the effect of total reflections are explicitly shown, and the corrected edge diffracted wave term is singled out and numerically calculated.

SPECTRAL-ITERATIVE ANALYSIS OF
DIELECTRIC ROD ANTENNAS

S. Ray and R. Mittra
Department of Electrical Engineering and
The Coordinated Science Laboratory
Urbana, IL 61801

The spectral-iterative technique (SIT) has recently been developed to analyze scattering from arbitrary bodies (Kastner and Mittra, AP-S International Symposium Digest, June 1981). For scattering applications the SIT is a numerically efficient alternative to moment methods for bodies larger than a wavelength. In this paper we extend the SIT to the analysis of a dielectric rod (two dimensional) antenna. The TE case is treated here.

In this method the field on the guide is regarded as being generated by a source inside the waveguide. This source, proportional to the polarization P, is algebraically related to the E-field via a constitutive relationship. When the field and source are Fourier transformed in the transverse spatial coordinate we obtain a second relationship between them. The transformed E-field is a convolution in the longitudinal spatial variable of the spectral domain source and the one dimensional free-space Green's function. By sampling the field and source at closely spaced transverse planes, an algebraic approximation to the convolution integral is obtained. The resulting expression is numerically efficient due to its recursive nature and is very accurate. We construct an iterative solution by first guessing a field distribution. Alternately computing the spatial domain constitutive relation and the spectral domain expression generates an updated field distribution. The FFT algorithm provides a convenient means of relating these two expressions. This procedure systematically improves the accuracy of the solution and is repeated until convergence is obtained.

A modification of the above procedure is required as the terminated rod is a semi-infinite structure. To avoid a numerical convolution over a semi-infinite range, part of the integral is treated analytically. This portion of the convolution contains R, the reflection coefficient on the guide, as an unknown constant. A procedure for updating the initial guess for R is incorporated in the iterative scheme.

Computed values for the reflection coefficients, aperture distributions, and far-field patterns are presented. Convergence properties are discussed. Important features of the SIT are its simple formulation and the inherent check of constitutive and boundary conditions. The method is readily generalized to more complex geometries.

THE SELF-TERM CONTRIBUTION FOR TIME-DOMAIN INTEGRAL EQUATIONS

N.J. Damaskos, R.T. Brown, J.R. Jameson
NJDI, Box 469, Concordville, PA 19331

and

P.L.E. Uslenghi
University of Illinois at Chicago

The electric field integral equation in the time domain requires special care in evaluating the initial value of the surface current density $\underline{K}(\underline{r},t)$ at the time $t = t_0$ when the incident pulse first reaches an observation point $\underline{r}$ on the surface of the scatterer; later values of $\underline{K}$ are easily obtained by stepping in time. Initially, the incident field $\underline{E}^i(\underline{r},t_{0+})$ must be cancelled by that portion of the integral over $\underline{K}$ for which $t \approx t_{0+}$. In the literature (see, e.g., R. Mittra, chapter in Transient Electromagnetic Fields, ed. L.B. Felsen, Springer, 1976, and references therein), a small surface area is chosen around $\underline{r}$, and the contribution of this self-cell to the integral is evaluated analytically, to yield the initial value of $\partial\underline{K}/\partial t$ as a function of the initial value of $\underline{E}^i$. Although this approach is numerically successful, it is physically unsatisfactory because the initial value of $\partial\underline{K}/\partial t$ depends on the cell size.

In this paper, we give an alternate approach which does eliminate the above inconsistency. We develop both $\underline{E}^i$ and $\underline{K}$ in Taylor series for $t > t_0$ and substitute them into the EFIE. A careful limit process for $t \to t_{0+}$ yields an initial value of $\partial\underline{K}/\partial t$ which depends on the initial value of $\partial E^i/\partial t$ and on the angle α of incidence of the primary wave at $\underline{r}$, but is independent of cell size.

Numerical results based on the above initial estimate are given, and the problem of cancellation of the initial field on the shadowed portion of the scattering surface is discussed.

NUMERICAL INVESTIGATIONS OF AN EXACT SOLUTION TO THE DIRECT SCATTERING PROBLEM IN SPATIAL/FREQUENCY TIME SPACE

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

Recently, N. N. Bojarski has developed an exact, closed form (non-iterative) solution for the direct scattering problem. This solution reduces the problem to the solution of a set of two simultaneous linear algebraic equations, one in real space and the other in spatial frequency space. These equations are solved using a discrete stepping in time process. A major advantage of this solution is its computational efficiency. Let L be the number of time steps, and N the total number of spatial samples (e.g., $N = N_x * N_y * N_z$ for a three dimensional problem). Then it is shown that the number of complex multiply/add operations is of the order of LN $\log_2$ N, and of the order of LN storage locations are required. This paper verifies this efficiency with several one and two dimensional examples, and derives several results concerning the effect of error propagation on the solution.

Numerical examples of the computation of scattering in lossless, nondispersive inhomogeneous media are presented. As one example of the magnitude of problem which the computational efficiency of the solution makes practical on even small machines, a one dimensional problem with N = 256 required ~2 minutes of cpu time, and the same problem with N = L = 1024 required ~36 minutes. These problems were run on a VAX 11/780 virtual storage system with floating point accelerator in interactive mode on a system supporting 12 users, and the times given include all problem overhead and all time required to generate plotted output (estimated to represent ~30% of the cpu time for the N = 256 case, and ~25% of the time for the N = 1024 case). Furthermore, no attempt was made to optimize the FFT routine employed for operation in a paged virtual memory environment. Lack of such optimization can increase running time by as much as a factor of 10 for problems of size N = 1024. No special purpose array processing hardware was employed. Results and timings for larger, two dimensional problems are presented, along with data to permit extrapolation of performance to larger computers.

It is shown that the solution is stable with respect to the propagation of computational errors. The relationships among the time and spatial sampling sizes, and the resolution of the solution, are presented.

K-SPACE FORMULATION OF THE SCATTERING PROBLEM IN THE TIME DOMAIN FOR VERY LARGE PROBLEMS

Norbert N. Bojarski
16 Pine Valley Lane
Newport Beach, California 92660
Telephone: (714) 640 7900

The arbitrary direct scattering problem is solved numerically in closed form in the time domain and spatial Fourier transform space. This solution consists of casting the general basic global laws (i.e., the second order partial differential wave equation or its integral representation) as a local algebraic equation in the spatial Fourier transform space, and leaving the specific local constitutive equations (i.e., the algebraic boundary conditions, which specify a given structure, which are conventionally imposed on the differential or integral representation of the genaral basic global wave equation) as a local algebraic equation in real space, thereby reducing the scattering problem to a statement of two simultaneous local algebraic equations in two unknowns (the fields and the induced sources) in two spaces connected by the spatial Fourier transform. By virtue of causality, a numerically efficient closed form solution to this set of equations is obtained that utilizes the fast Fourier transform algorithm as the transformations between the two spaces. By virtue of the numerically efficient fast Fourier transform algorithm and the local algebraic representations, the number of required complex multiply-add operations and storage allocation is of the order of $N\log_2 N$ and N per temporal descretization respectively (where N is the number of spatial cells into which the scattering problem is descretized). It is shown that the solution is only of the order of $\log_2 N$ slower than an ideal solution. The solution is thus practical for very large one, two, and three dimensional scattering problems. Numerico-experimental results for very large two dimensional problems are presented cinematographically.

ELECTROMAGNETIC WAVE SCATTERING BY THIN HELICAL WIRES

A. Sezginer and J. A. Kong
Department of Electrical Engineering and
Computer Science and Research Laboratory
of Electronics
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Electromagnetic wave scattering by thin wire helicies has been scarcely studied in the literature although guidance and radiation problems involving helical structures have been extensively treated in relation to traveling wave tubes and helical antennas.

We apply the physical optics approach to obtain an integral representation of the scattered field which asymptotically approaches to the geometrical optics result in the high frequency limit. The physical optics approximation to the induced current needs to be supplemented by the guided wave terms so that the boundary conditions of vanishing current at the two ends of the helix are satisfied. However, when the helical wire length is an integral multiple of half of the incident wavelength, superposition of the guided waves no longer satisfies the boundary conditions. We resort to Galerkin's method with full domain basis functions in this case.

Validity of the physical optics approach is checked against Galerkin's method and experimental data for the case of a finite helix, and the modal approach (Sensiper, S., 1951, RLE Tech. Rep. 194, MIT) for helicies of infinite extent.

We conclude that the physical optics approach provides lucid physical interpretation, and very efficient and reasonably accurate means of computation.

NUMERICAL ANALYSES OF NONCANONICAL MICROSTRIP ANTENNAS

J. J. H. Wang
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

Numerical analyses of noncanonical microstrip antennas were conducted to seek a better understanding and hence performance improvements for these antennas. The equivalent electric and magnetic currents on the peripheral edge of the arbitrarily-shaped microstrip is solved by enforcing a boundary condition on the surface of the microstrip antenna. The fields due to these equivalent currents are computed by known integral expressions to yield the elements of the matrix, which is numerically solved for the unknown currents.

The efficiency in computing the fields due to sources in a dielectric layer backed by a perfectly conducting ground plane is essential to this numerical approach. Several special features and advantages of this approach are discussed in comparison with other numerical methods such as the Green's function (both scalar and dyadic) approaches, the finite element method, the segmentation and desegmentation method, and the wire-grid modeling techniques.

COMPUTATION OF FIELDS INSIDE LOSSY, INHOMOGENEOUS, DIELECTRIC BODIES

D.H. Schaubert*, D.R. Wilton† and A.W. Glisson†

*Division of Electronic Products, Bureau of Radiological Health, Rockville, MD 20857

†Department of Electrical Engineering, University of Mississippi, University, MS 38677

Several numerical methods have been developed for treating the problem of scattering and absorption by lossy, inhomogeneous, dielectric bodies. Among the methods that are based on integral equation formulations, the recently developed tetrahedral cell technique offers the greatest flexibility in modelling arbitrarily shaped bodies. The special basis functions defined on tetrahedral domains ensure continuity of conduction-plus-displacement current normal to interfaces between tetrahedral cells containing different media and they have constant divergence (charge density) in each cell.

This paper describes recent computational results obtained by using the tetrahedral cell method. The computed electric fields inside layered, dielectric spheres ($ka \simeq 1$) agree quite well with the results obtained from the modal solution. Several examples will be presented and the accuracy of the method for these will be discussed. Some of the results will be compared to those obtained by using other numerical methods. Some of the modelling considerations for tetrahedral cells also will be discussed.

ANALYSIS AND DESIGN OF MULTI-LAYERED, LOSSY, DIELECTRIC RADOME

TE-KAO WU AND DARRELL L. HELMS
ECI/E-SYSTEMS
P.O. BOX 12248, ST. PETERSBURG, FL

Analytical formulas for evaluating the transmission and reflection coefficients of plane waves through a 3-layered, lossless dielectric radome can be found in (Jasik, Antenna Engineering Handbook, Chap. 32, 1961). It should be noted that the above mentioned formulas are not useful for lossy dielectric materials. In this paper, a simple iteration method employing the invarient imbedding concept is presented to analyze the multi-layered, lossy dielectric radome. The invarient imbedding concept has been used previously (Pogorzelski and Wu, Proc. URSI Symp. EM Wave Theory, 323-325, 1977) to treat a 5-layered, lossy dielectric elliptical cylinder. For a multi-layered, lossy dielectric planar radome, the complicated moment matrices reduce to a simple 2 X 2 matrix. The transmission or reflection coefficients may next be calculated by simple matrix multiplications. Numerical results are obtained for an A-sandwich radome and agree excellently with the results shown in Jasik's book. (It is interesting to note that Jasik's book did present results for lossy dielectric materials, however, the formulas were only valid for lossless dielectric materials.) Extensive results are also obtained using this iteration method which yields valuable radome electrical design information.

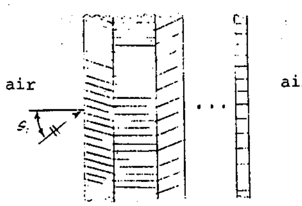


Figure 1. Plane wave illuminated, multi-layered dielectric slab.

MODAL INVESTIGATION OF MICROGUIDE

David C. Chang and Bing-Hope Liu
Electromagnetics Laboratory
Department of Electrical Engineering
University of Colorado
Boulder, Colorado 80309

Closely related both to some familiar microwave transmission lines like coplanar waveguide, coplanar strips, and suspended microstrip, and to the dielectric slab used in the optical frequency range, the single conductor strip on a dielectric substrate ("microguide") is suggested now and again as a guiding and/or structure for the radiating millimeter-wave integrated antenna system application.

In this report, the rigorous hybrid-mode solution to the Maxwell's equations will be given in the Fourier transform domain, leading to a system of spectral domain equations, which is then solved by the Galerkin's method. The basis functions carefully constructed for the surface current components on the conductor strip have the quasi-eigenfunction properties and therefore result in very fast convergence. The range of existence of the discrete non-radiating waveguide modes will be given in terms of a suitable interval for the propagation constant β. The frequency-dependent lower limit of this interval is determined by the surface wave factors which occur in the spectral domain equations mentioned above and represent TM or TE type of surface waves associated with the substrate. The dependence of the cutoff of waveguide mode, defined by the requirement of exponential decay of fields in the transversal directions, on the microguide geometry will be discussed. Comparison to some related guiding and radiating structures will be made. Practical application considerations will be given.

LOW FREQUENCY SCATTERING BY METALLIC PLATES: A CRITIQUE

Thomas B.A. Senior
Electrical and Computer Engineering Department
University of Michigan
Ann Arbor, MI 48109

When a finite, infinitesimally thin, perfectly conducting flat plate is illuminated by a low frequency electromagnetic wave, the leading (Rayleigh) term in the far field expansion is attributable to induced electric and magnetic dipoles. The electric dipole moment can be expressed in terms of an electrostatic potential which is given by an integral equation whose solution is relatively easy to obtain numerically. Similarly, the magnetic dipole moment is a weighted integral of a magnetostatic potential, but the usual equation for this is an integro-differential equation involving a surface Laplacian.

To avoid the complications associated with this, Mittra and his co-workers have proposed integrating out the operator by introducing an appropriate (unknown) function on the right-hand side of the equation. In the particular case of the zeroth-order magnetic field, the result is two integral equations for the tangential components of the current with simple first-order polynomials in the surface coordinates x and y on the right-hand sides(Y. Rahmat-Samii and R. Mittra, IEEE Trans. Antenna and Propagat. 25, 180-187, 1977). The consequences of this approach are explored. It is shown to imply a connection between the electric and magnetic dipole moments which is valid for elliptical plates (of which the disk is a special case), but is in violation of the known numerical results for other plates including rectangular ones. Thus the specific approach used by Rahmat-Samii and Mittra is not, in general, valid.

RADAR CROSS-SECTIONS OF OPEN-ENDED
CIRCULAR METALLIC CYLINDERS

Captain Thomas W. Johnson
Department of Electrical Engineering
U.S. Air Force Institute of Technology
Wright-Patterson AFB, OH 45433

Scattering from open-ended circular metallic cylinders is approached via the Wiener-Hopf Technique. A prior report (Johnson & Moffatt, National Radio Science Meeting, 16-19 June 1981) dealt with numerical methods to calculate the Wiener-Hopf factorization functions in various frequency regimes and with various values of the factorization variable α. In this paper, these methods are used to obtain numerical results. The monostatic radar cross-section for open-ended circular cylinders, both empty and terminated in a flat conducting plate, are calculated for a variety of frequencies and orientations, and compared to empirical results.

FORMULATION OF THE ELECTROMAGNETIC SCATTERING
BY A RESISTIVE WEDGE USING THE KONTOROVICH-LEBEDEV TRANSFORM

Ivan J. LaHaie
Radar and Optics Division
Environmental Research Institute of Michigan
P.O. Box 8618
Ann Arbor, Michigan 48107

The electromagnetic scattering of an E- and H-polarized plane wave normally incident upon a resistive wedge is formulated using the Kontorovich-Lebedev (K-L) transform. By decomposing the fields into components which are symmetric and antisymmetric about the bisector of the wedge, the transformed resistive boundary conditions lead to four uncoupled functional equations for the four transformed unknowns (two for each polarization). By restricting the included angle of the wedge, the functional equations can be expressed in two forms: as linear, second order difference equations with variable coefficients, or, by applying a technique developed by the author, as Fredholm integral equations of the second kind over the Banach Space of bounded, continuous functions on a semi-infinite line. The former are not amenable to solution using standard techniques, but the latter admit a uniformly convergent Newman series expansion in powers of $1/\eta$ for E-polarization, and in powers of η for H-polarization where η is the normalized resistivity. Bounds for the radii of convergence of the series are developed which are functions of the included angle of the wedge. The uniform convergence of the series allows the inverse K-L transform to be applied on a term-by-term basis, thus generating a similar series for the scattered fields. Within the bounds developed, there are no values of η for which the series converge simultaneously for both polarizations, and hence the results cannot be justifiably applied to an arbitrarily polarized incident plane wave.

Analytic Considerations for Calculating the Complex Reflection Characteristics of Conducting Mesh Antenna Surfaces

J.C. Brand, J.F. Kauffman
North Carolina State University
Raleigh, NC 27650

Mesh antenna surfaces formed from thin conducting fibers must exhibit very good complex reflection characteristics for the antenna system to perform well. The determination of these characteristics have been reported [M. Kontorovich, Radio Engineering and Electronic Physics, Vol. 8, No. 9] for square gratings in terms of averaged boundary conditions and measured data [M. Astrakhan, Telecommunications and Radio Engineering, Vol. 9, No. 8]. However, actual knitted mesh surfaces have a different physical configuration than those examined in the above references and as such exhibit somewhat different reflection characteristics.

The complex reflectivity of a mesh surface can be tested by placing mesh samples in a waveguide balanced bridge test unit and comparing the results with a standard. The data from these samples is found to differ from that determined analytically, especially as the frequency is increased. Reasons for this discrepancy are explored and explanations are offered to account for the observed differences. A formulation to increase the accuracy of the approximate analytical expressions for complex reflectivity of mesh surfaces is introduced and the method of applying this technique is outlined.

RADAR TARGET BACKSCATTERING MATRICES FOR TIME VARYING POLARIZATIONS

John D. Nordgard
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332

Abstract

The characteristics of the electromagnetic waves backscattered from the conducting surfaces of a radar target are determined theoretically and confirmed experimentally by a method which allows for arbitrary time varying states of polarization of the incident wave. Sets of time varying polarization basis vectors are introduced to characterize the changing states of polarization of the incident and scattered waves. These sets of basis vectors are used with the stationary backscattering matrix of the target to characterize the scattering properties of the target as a function of the time varying parameters of the incident electromagnetic wave. The final form of the backscattering matrix is referred to several conveniently chosen rotating coordinate systems.

This method is applied to the problem of radar target identification. Examples are cited for incident monocromatic uniform TEM waves with several special states of polarization, viz. linear, rotating linear, circular, elliptical, and rotating elliptical. Backscatter from flat plates, right dihedral and trihedral corner reflectors, and thin wires is considered. Only target polarization characteristics are of interest; target area and range effects are not considered. The theoretical predictions are confirmed by experimental measurements.

SEVERAL SIGNIFICANT FACTORS AFFECTING MODELS FOR SCATTERING FROM ROUGH SURFACES

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

This paper discusses how three different factors affect the description of EM wave scattering from rough surfaces. These are the precise definition of the glistening surface, the variation of the scattered power for different height distributions and the moisture level in the terrain. For each of these factors, the effect is highly sensitive to surface roughness.

The respective influences are calculated using a model for the specular and diffuse scattering from rough terrain which incorporates statistical parameter estimation applied to digitized terrain data bases. The terrain is divided into homogeneous, isotropic, rectangular cells, that are each characterized by a mean height, variance, degree of correlation, statistical height distribution, and an appropriate dielectric constant. The model includes spatial inhomogeneities from cell to cell, multiple specular reflection points, and global and local shadowing with explicit shadowing functions for Gaussian and exponentialy distributed surface heights. The antenna power patterns of both the transmitter and monopulse receiver are included in the model, and signal processing losses can be considered.

The first roughness dependent effect discussed here is that of the glistening surface. For some parameter ranges, the classical definition of the glistening surface as given by Beckmann and Spizzichino is not adequate. Their definition does not account for the angular dependence of the scattering matrix in the expression for σ_0 (the normalized cross section of the rough surface). In addition, it may suppress contributions from areas close to the antennas. In the second instance, the usual form of the cross section formulation is based on physical optics and the asymptotic evaluation of integrals representing σ_0 in the limit of very rough surfaces for bivariate Gaussian and exponential surface height distributions. In the exponential case, the uncorrelated variates are not independent and, for intermediate levels of roughness, this leads to a form for σ_0 different from the usual result. Finally, the dielectric constant of the surface, for a range of conditions, is chosen to correspond to arid, normal, and very wet soil. The effect is again sensitive to the degree of roughness level.

SCATTERING CHRACTERISTICS OF SAND PARTICLES

A. Kumar
Department of Electrical Engineering
Lanchester Polytechnic
Coventry CV1 5FB
England

The aim of this research work is to measure the extinction cross-section of individual falling wet and dry sand particles at 35 GHz to find out the veracity of Mie theory values. It has been also determined the effect of the shape of the wet and dry sand partcles and canting angle on scattering and depolarization.

We have used the open-resonator for this experiment. The resonator consists two spherical mirrors of radius of curvature of r, separated by a distance d. The resonator has very high Q-factor, with a Gaussian radial field distribution as described in ref. 1. A family of TEM_{pql} mode can exist, pql giving the number of radial, circumferential and axial field variations respectively. The resonant frequency of the system is given by

$$f_{plq} = \frac{c}{2d}\left[(q + 1) + \left(\frac{1}{\pi} \cos^{-1}\left(1 - \frac{d}{r}\right)\right)(2p + l + 1)\right]$$

where c is the velocity of light.

The measurement of extinction cross-section depends upon measuring the effect of scattering particle on the Q-factor of the resonator. The extinction cross-section is given by

$$\sigma = \frac{\pi d}{4} (d (2r - d))^{\frac{1}{2}} \left\{ \frac{1}{Q_1} + \frac{1}{Q_2} - \frac{2}{Q_o} \right\}$$

where Q_o is the Q-factor of the empty resonator, Q_1 and Q_2 are the Q-factors for each of the two positions (quarter wavelength apart) of the sand particle.

The experimental system, measurements, results, applications and experimental errors have been discussed in detail.

References

1 A.L Cullen and A. Kumar, Proc. Roy. Soc., A-315, 217-230, 1970.

ANALYSIS OF INTERNALLY REFLECTED WAVES CREATING A DOUBLE HALO IN ELECTROMAGNETIC SCATTERING BY DIELECTRIC SPHEROIDS

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

Fredrick B. Sleator
Cancer Centre, Medical Sciences Campus
University of Puerto Rico
San Juan, Puerto Rico

Wolfgang-M. Boerner
Communications Laboratory
Information Engineering Department
University of Illinois at Chicago Circle
P. O. Box 4348
Chicago, Illinois 60680

In case of a spherical structure, due to the symmetry, the conditions for existence of glory rays and internal surface rays are straight forward. It will be shown that for the prolate spheroid, with arbitrary direction of incidence, one has to resort to a numerical method of ray tracing. The solution of this numerical method, along with some geometrical arguments, show that for most of the cases of arbitrary scatterers, the single bounce glory ray will not exist and, therefore, will not contribute to the back-scattering energy. Similarly, the conditions for the existence of internal surface waves will be presented. Various other internally reflected rays which contribute to the backscatter energy and were not reported by earlier investigators (probably because they do not exist for spherical scatters) will also be presented. Specific emphasis will be placed on that family of internally reflected waves creating a double halo.

Diffraction of a Line Sink Field

Lars Falk
National Defence Research Institute,
Linköping, Sweden

Abstract

The problem of a line sink field scattered by a halfplane is solved by rigorously performing a transformation of the corresponding solution for a line source. The result is useful as an approximation for edge diffraction of converging rays. It also provides a very simple illustration of the field geometry at a real caustic.

ANTENNA SITING STUDIES

James W. Coffey
Robert J. Papa
Electromagnetic Sciences Division
Rome Air Development Center
Hanscom AFB, MA 01731

This paper is concerned with two subjects: (a) the effect of specular scatterers on the sidelobe level of an antenna and (b) the response of a missile to the main beam scattered power and sidelobe radiation of an antenna in the presence of one or several specular scatterers.

A technique for predicting the effects of specular reflectors on antenna performance has been developed. Laboratory testing of a low sidelobe antenna indicated an acceptable low sidelobe level. However, when the antenna was field tested, it exhibited average radiated power levels off the main beam which were significantly greater than those anticipated. In an effort to determine the cause of this increase, a computer model of an antenna in a field site was developed. This simulation model includes the calculation of the total scattered power of the antenna main beam and sidelobes from specular reflectors distributed over both the near and far fields of the antenna. The specular reflectors are metallic right circular cylinders. Most of the parametric studies assume random location of the cylinders in the far field of the antenna. Preliminary results have verified observations made during field testing. The effect of evanescent waves on the scattering mechanism when a single right circular cylinder is located in the near field of the antenna is studied (R. Rante, Private Communication). This model is the basis for a study of a missile homing into the point at which the net maximum radiated power of an antenna is located. The presence of large specular scatterers is considered. For different configurations of cylinder locations, the trajectory of a missile is studied as the antenna rotates.

On Bandlimited Proximates in Antenna Theory

S. Chaiken, G. Franceschetti and N.G. Alexopoulos
Department of Electrical Sciences and Engineering
University of California, Los Angeles, CA 90024

A new iterative algorithm (Youla, D., IEEE trans. CAS-25, #9, 1978) for the numerical analytic continuation of bandlimited functions is discussed in connection with two problems in antenna design and synthesis. The first concerns the general problem of pattern synthesis. New techniques for total or partial pattern design subject to constraint (e.g. superdirectivity) are presented. The specific problem of finding constrained bandlimited proximates to a given visible pattern is used as example in a computationally facile setting. Comparison with other methods (e.g. Rhodes, D., IEEE trans. AP-11, #7, 1963) follow. Next, the theory of mutual coupling between canonical minimum scattering antennae (Wasylkiwskyj, W., and Kahn, W., IEEE trans., AP-18, #2, 1970) yields 1st order estimates of coupling from knowledge of the total antenna pattern function. The forced restriction of pattern measurement to the visible begs the question of total pattern reconstruction from its visible segment. On constraining the pattern function as bandlimited, we can provide a direct computation of its continuation. Numerical results and bounds are discussed.

Research Supported by U.S. Army Contract DAAG29-79-C-0050

THEORY AND APPLICATIONS OF AN INTERACTIVE COMPUTER-GRAPHIC APPROACH TO ANTENNA PATTERN SYNTHESIS

Francis J. Zucker
Electromagnetic Sciences Division
RADC/EEA
Hanscom AFB, MA 01731

Antenna power pattern synthesis methods aimed at equal-decibel ripple approximations have been known for some time. In the present approach, which continues a development initiated by K.G. Ramsey (Westinghouse), the lowest-order Chebyshev polynomial (or associated Taylor distribution) compatible with both the steepest roll-off and the lowest sidelobe level in the prescribed pattern is first selected. The nulls of this polynomial are then relocated, using an iterative, interactive computer-graphic procedure, until the approximation is satisfactory. Results are critically dependent on optimizing the sequence of relocations.

As an example, the synthesis of a satellite link antenna in a proliferated environment is shown, and comparison made in terms of bandwidth and ease of physical realizability with an antenna design based on conventional amplitude pattern synthesis.

To improve physical understanding of the procedure, the extremely low sidelobe "filler patterns" produced by the null relocations are exhibited. Also, a comparison-in-principle is made between our quasi-sampling procedure and normal sampling with Chebyshev functions.

BANDWIDTH LIMITATIONS ON THE YAGI HYBRID ANTENNA

J. M. Tranquilla

and

M. J. LeBlanc

University of New Brunswick
Department of Electrical Engineering
Fredericton, New Brunswick, Canada
(506) - 453-4561

Abstract

The Yagi hybrid antenna has been suggested (W. K. Kahn, IEEE Trans. Ant. Prop., AP-29, 3, pp. 530-532, 1981) as a design which could incorporate the broadband features of the log-periodic dipole array with the beamwidth and gain advantages of the Yagi resulting in an antenna which would have lower sidelobe levels than the Yagi. Both theoretical and experimental analysis of this antenna indicates that increasing the number of equal length parasitic elements results in an increase in endfire directivity, and increase in the passband front-to-back ratio, a decrease in the bandwidth, and the occurrence of resonance phenomena characteristic of a parasitic array approaching cutoff. Techniques which have proven successful in suppressing resonant behaviour on Yagi arrays are shown to be directly applicable to the Yagi hybrid design.

ON THE NUMERICAL COMPUTATION OF THE WIDE ANGLE SCAN CHARACTERISTICS OF A CASSEGRAIN REFLECTOR ANTENNA

Ronald J. Pogorzelski
TRW Defense and Space Systems Group
One Space Park
Redondo Beach, CA. 90278

Recently, a numerical technique was presented designed to efficiently evaluate the two dimensional aperture integral which arises in the physical optics formulation of the scattering from a hyperboloidal subreflector. (R. J. Pogorzelski, 1981 IEEE AP-S Symposium, Los Angeles, CA.) The technique involves use of Fourier expansion in the angular variable around the symmetry axis of the feed reflector system. Because of this the procedure presented loses much of its utility if the feed is scanned far from the symmetry axis of the reflector. This can be ascribed to the introduction of a rapid linear phase variation across the aperture which cannot be removed by straightforward application of the procedure.

In this paper a generalization of the previously described technique is presented. This generalization permits application to the case involving a feed far removed from the symmetry axis. Basically the rapid linear phase variation across the aperture is removed by multiplication by an appropriate complex exponential. As a consequence of this multiplication, the resulting Fourier series representation of the reflected field contains coefficients which depend on the angular variable of the expansions; a situation similar to that encountered previously by Wong (AP-21, 335-339, 1973). Were this representation merely summed and re-expanded into a Fourier series of the usual form, an inordinate number of harmonics would be required. However, if the center of expansion is displaced appropriately, the number of terms required is considerably reduced. (W. C. Wong, private communication).

SCATTERING BY TWO THIN PARALLEL CONDUCTING PROLATE SPHEROIDS EXCITED BY A RING MAGNETIC CURRENT AROUND ONE OF THE SPHEROIDS

B.P. Sinha and R.H. MacPhie
Department of Electrical Engineering
University of Waterloo
Waterloo, Ontario, Canada N2L 3G1

When a thin prolate spheroidal antenna is fed by a voltage source applied across a small centrally located gap on the antenna, the system can be replaced by the prolate spheroid without gap and a flat ring of magnetic current of appropriate magnitude situated at spheroidal coordinates($\xi=\xi_a,\eta=0$) surrounding the spheroid which we call spheroid A.

The problem investigated is the electromagnetic scattering from the ensemble of the thin prolate spheroid A and a second thin prolate spheroid B situated outside the magnetic current ring and in parallel configuration with respect to A, the source of excitation being the magnetic current.

The EM fields are expanded as series of appropriate prolate spheroidal basis functions using the translational addition theorem for spheroidal functions [B.P. Sinha and R.H. MacPhie, Quart. Appl. Math, Vol. 38, pp. 143-158, 1980]. The combination of the azimuthal symmetry of the source and the thinness of the spheroids results in a negligible Φ-component (cross-polarized) of the electric fields. Accordingly only the η- components of the total electric field is required to vanish on both spheroids (perfectly conducting).

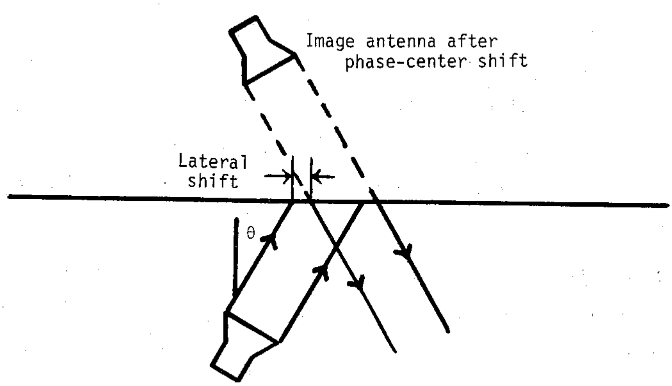
Numerical computations for scattering patterns in the far field are given for the cases when the centre to centre displacements of A and B are along mutually axial and broadside directions and the spheroids are each of resonant length (Approx. $\lambda/2$).

THE GOOS-HÄNCHEN SHIFT AS AN AVERAGE PHASE-CENTER SHIFT FOR AN ANTENNA EMBEDDED IN A DIELECTRIC HALF-SPACE

Arthur D. Yaghjian
Electromagnetic Fields Division
National Bureau of Standards
Boulder, Colorado 80303

An arbitrary transmitting antenna, characterized by its plane-wave spectrum, is embedded in a dielectric half-space. If multiple reflections between the antenna and the dielectric interface are neglected, the reflected and transmitted fields are found from a straightforward plane-wave representation of the tangential fields equated across the interface. Specifically, the reflected and transmitted spectra equal the original antenna spectrum weighted respectively by the proper reflected and transmitted Fresnel coefficients. From these reflected and transmitted spectra we trace the trajectory of the reflected and transmitted far-field phase centers for the image antennas as the far-field angle θ ranges from 0 to $\pi/2$.

For the reflected fields the shift in far-field phase center becomes infinite both for θ equal to the critical angle θ_c and for θ equal to $\pi/2$. However, when an average phase center for the mainbeam of directive antennas is defined, the shift in this average phase center remains finite for all angles of incidence including $\theta = \theta_c$ and $\pi/2$. Moreover, the shift in average phase center yields an extremely simple estimate of the Goos-Hänchen shift that remains valid for all angles of incidence, unlike previous formulas which fail either near the critical angle (θ_c) or at grazing incidence ($\pi/2$). Good agreement is found throughout the critical angle region with the lateral beam shift for Gaussian beams predicted by Horowitz and Tamir (J. Opt. Soc. Am., 61, 586-594, May 1971).



LOOP ANTENNAS FOR DIRECTIVE TRANSMISSION INTO A MATERIAL HALF SPACE

Glenn S. Smith and **Lam Nhat An***
School of Electrical Engineering
Georgia Institute of Technology
Atlanta, Georiga 30332

Abstract

The horizontal circular-loop and the two-element coaxial array of loops above a material half space are studied as antennas for directive transmission into the half space. In a practical situation, the loops might be located in air with the directive transmission into the earth.

Numerical calculations based on a rigorous theory (An and Smith, Radio Science, 1982) show that a resonant loop (circumference/wavelength = 1) produces a directive beam into the half space with the width of the beam decreasing as the dielectric constant of the half space is increased. To determine the optimum geometry for the single loop and the array, the far-zone field patterns and directivities of these antennas when placed over lossless dielectrics are considered first. The directive properties for the lossless dielectric are found to be indicative of those for the same antenna over the dielectric with moderate loss when proper account is taken of the exponential attenuation experienced in the lossy medium.

Parametric studies are used to obtain the maximum directivities for these antennas. For the single loop the optimum height over the interface is determined, and for the two element array, consisting of a driven loop with a single parasite, the optimum size and spacing of the parasitic reflector are found.

Measured electric field patterns of model antennas above an interface between air and fresh water are in good agreement with the theoretical results.

*Now with Bell Telephone Laboratories, Holmdel, New Jersey 07733.

ELEVATION STEERING OF THE PATTERN OF A VERTICAL ARRAY OVER AN INHOMOGENEOUS GROUND SYSTEM

N. C. Mathur, R. J. King and C. J. Teng*
Department of Electrical and Computer Engineering
University of Wisconsin, Madison, WI 53706
*M. I. T. Lincoln Laboratory, Lexignton, MA 02173

Because of the importance of elevation angles-of-arrival in HF over-the-horizon radar and other propagation studies, the behavior of the radiation pattern of a vertical array erected on an inhomogeneous ground system is very important. The ground has a significant effect on the radiation pattern. In this paper, the radiation pattern of a vertical array of short vertical dipoles has been studied. The ground system consists of a number of radial wires spread on the ground in an azimuthally symmetric manner. The radiation pattern of a single short vertical dipole over such a ground system is evaluated numerically using a recent formulation of Teng and King (Electromagnetics, 1, 101-116, 1981). In this formulation the compensation theorem is used to derive expressions for the radiation field in the presence of an azimuthally symmetric ground of known surface impedance. The surface impedance of the earth with a radial wire ground system is found by using the shunt impedance method of Wait (IRE Trans. Ant. Prop., AP-10, 530-542, 1962).

The behavior of a 21-element array of height 2λ over well-conducting earth ($\sigma = 10^{-2}$ s/m, $\varepsilon = 15\varepsilon_0$) having 120 radial wires of length 2λ is studied. Because of the complex nature of the fields of a dipole over such a ground system, the illumination function for the array aperture which will produce an optimum pattern is not known. Following Waldman (IEEE Trans. Ant. Prop., AP-18, 105-107, 1970), we have used for the illumination function the complex conjugate of the field of the dipoles in the direction of steering. It is found that the beam cannot be steered to an elevation angle less than 9°. The illumination function has little influence on the shape and position of the main beam. It does influence the sidelobe structure. The inhomogeneous earth results in a broadening of the beam by about 30% over that of the same array over a perfectly conducting earth. Other aspects of the influence of the ground system and illumination function on the array pattern and steerability are discussed.

CONCERNING THE SCIENTIFIC BASIS FOR NOISE AND INTERFERENCE CONTROL

Carl E. Baum
Air Force Weapons Laboratory
Kirtland AFB NM 87117

Complex electronic systems can be vulnerable to various kinds of electromagnetic environments. It is a very challenging task to have a detailed understanding of all the resulting signals at all places of importance in the system. In order to control these signals and bring them all below some particular levels with a high confidence, it is necessary to have some general techniques to control the electromagnetic interaction with the system as a whole and reduce the number of critical variables which govern the system response. To begin this discussion of the scientific basis for noise and interference control one can consider three basic ideas which are not totally independent: electromagnetic topology, symmetry, and orthogonality.

Electromagnetic topology has both qualitative and quantitative aspects. The qualitative side includes the hierarchical volume/surface topology and the equivalent dual graph or interaction sequence diagram. This aspect leads to design guidelines for shielding penetratons and discrete shielding concepts which involve combinatoric considerations. On the quantitative side one begins with the BLT equation for signal transport through the system and partitions the terms according to the hierarchical topology to form supermatrices and supervectors with special properties. Assuming effective shields and subshields one obtains the good-shielding approximation as an approximate solution to the BLT equation. Combining this with norm concepts gives bounds on signals in the various system layers. This gives a format for specifying the performance of the important elements controlling the electromagnetic penetration.

Geometrical symmetries, such as a symmetry plane, can be used to decompose the system response into terms which respond in different ways to the electromagnetic excitation. By imposing corresponding symmetry conditions on the exciting field certain undesired response terms can be suppressed. A simple example of this concept is cross polarization.

One can think of orthogonality in a simple form as two vectors at right angles to each other as in cross polarization. However, one can more generally think of orthogonality by extending the concept of dot product to symmetric product involving integration of dot products of vector functions over various domains. Since such symmetric products appear in modal coefficients (both eigenmodes and natural modes) then orthogonality is interpretable as zero modal coefficients which provides an alternate interpretation of the use of symmetry to cancel certain responses. Furthermore shielding as used in electromagnetic topology can be interpreted as making coupling coeeficients to internal modes small giving a concept of "approximately orthogonal".

APPLICATION OF SHIELD TOPOLOGY TO SYSTEM PROTECTION

Edward F. Vance and Werner Graf
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

The protection of electronic systems from strong external sources of electromagnetic stress such as lightning and the EMP, requires a systematic application of closed electromagnetic barriers between the source and the protected circuits. Because systems are often constructed by integrating packaged electronic equipment and subsystems into airframes, ships, or ground based facilities, the protection is usually allocated between a system level barrier and an equipment level barrier. In this paper we discuss some implications of the choice of circuit threshold, of the ability to test or evaluate the protection, and of the ability to specify thresholds on the procedures for allocating barrier effectiveness.

The system barrier must at least reduce the stress applied to the protected circuit to below the damage level, but there is no benefit from barrier improvement that reduces the threat stress to much below the stress that the system itself generates during the normal operation. The use of damage as the threshold for unsatisfactory performance is contingent upon the damaged condition being accurately defined. However, only the functional (and not the damage) characteristics of devices are usually carefully controlled. Hence the damage threshold often cannot be accurately defined, and sometimes may vary over several orders of magnitude among different lots or different manufacturers of functionally interchangeable parts. Furthermore, the damage threshold can rarely be determined without destroying the unit being tested.

The ability to specify and test a barrier is affected by the shape, size, and complexity of the barrier, as well as by the threshold. More accurate source simulation or more thorough analysis are required to evaluate barriers having many arms, branches, or extensions than to evaluate barriers of simple shapes such as cubes or spheroids. In addition, since for every n penetrating conductors there are n^2 modes of excitation, the choice of a barrier surface that minimizes the number of required penetrating conductors will also make specifications and evaluations of the barrier (or equipment immunity) easier. Since damage in general implies nonlinear behavior, the specification and evaluation of the equipment level barrier is further exacerbated if the damage threshold is chosen, because then either the nonlinear behavior of the equipment must be well understood, or the details of the threat and its interaction with the system level structure must be thoroughly understood, if confidence in the evaluation of the nonlinear events is to be gained.

USE OF TOPOLOGICAL DECOMPOSITION CONCEPTS FOR DETERMINING EMP HARDNESS ALLOCATIONS FOR MULTI-SHIELDED SYSTEMS

Frederick M. Tesche
LuTech, Inc.
P.O. Box 1263
Berkeley, CA 94701

ABSTRACT

Topological shielding concepts may be applied to the design of an EMP hardened system in order to insure that the shielding design is consistent and that the chances of a shield failure are minimized. A topologically consistent design requires that all electromagnetic shields within the system be closed, and that all penetrations into a shielded region be provided with some form of EMP protection.

In carrying out a design for a particular system, it is desired to use a balanced hardening approach. This implies that the levels of EMP protection at each penetration point within the topological layers are chosen in such a way so that the responses within the system are comprised of roughly equal contributions from each POE.

The topological decomposition of a system permits the determination of the appropriate amounts of required hardness at each POE. This is known as developing hardness allocations for the system. Often, this process is carried out by considering only one class of penetrations, and neglects the effects of the others. For example, a shielded enclosure is frequently described in terms of a "shielding effectiveness" for incident electromagnetic fields, neglecting the effects of conducting penetrations which usually contribute substantially to the internal response.

This paper will review the topological concepts of shielding, and illustrate how they may be applied to a groundbase system. Special attention will be paid to the methodology of developing a rational scheme of EMP hardening allocation at the various POEs in the shielding topology.

SOME ASPECTS OF EMP SPECIFICATIONS

W.S. Kehrer

Air Force Weapons Laboratory
Kirtland AFB, N.M.

L. Marin

The Dikewood Corporation
Santa Monica, California 90405

Specifications form one tool in the overall process of establishing/achieving/validating that a system is hard to EMP. Requirements that specifications must satisfy in order to serve different purposes in the overall hardening process will be discussed. Issues to be covered include

- Quantities to be used in specifications
- Locations in a system where to apply specifications
- Subsystem versus system-level specifications
- Specifications and hardness validation schemes

The use of existing system-level EMP test data in defining specifications is also discussed.

AN EXACT, COMPULATIONALLY EFFICIENT SOLUTION TO THE INVERSE SOURCE/INVERSE SCATTERING PROBLEM IN SPATIAL FREQUENCY/TIME SPACE

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

Recently, N. N. Bojarski has discovered a new, exact, computationally efficient solution to the direct scattering problem. The author has discovered a closed form solution to the inverse scattering problem which has similar properties. The basic wave equation is obtained as an algebraic equation is the spatial frequency domain (but with the temporal variable left untransformed). The constituative relations, which include the unknown medium properties as a function of the spatial variables, are written as algebraic equations in real space. The result is a set of two simultaneous algebraic equations in two spaces connected by the spatial Fourier transform. These equations are local in the spatial varible, but global in the time variable. A temporally local form of these equations is obtained. By the proper application of causality and other real world constraints, a numerically efficient, exact closed form (non-iterative) solution to the inverse problem is obtained. In their present form, the solutions for the direct and inverse problems are exact for media with arbitrary spatial inhomogeneities but with no loss or dispersion. A method for extending both of these solutions to more general media is presented.

The emphasis of this paper is on the properties of this solution, rather than on the details of its derivation. The computational efficiency of the new solution is significant. It is shown that if L is the number of time steps and N is the total number of spatial resolution cells (e.g. $N = N_x N_y N_z$ for a problem with three spatial dimensions), the number of complex multiply/add operations required to solve the inverse problem is of the order of LN $\log_2$ N. The number of storage locations required is of the order of LN. This should be contrasted with operation counts and storage requirements of the order of LN^2 or higher <u>per iteration</u> for other available techniques. The consequences of this property of the solution are to make it quite feasible to process large amounts of data for real world, two and three dimensional problems in quasi-real time on realitively small computers.

The behavior of the solution in the presence of noisy, sampled data is discussed. It is shown that the solution is stable in the presence of noise. The relationship among signal-to-noise ratio, spatial sampling interval, and spatial resolution of the solution is presented. It is shown that resolution beyond the classical Rayleigh criterion may be achieved in practical cases. The uniqueness of the solution is discussed.

Numerical experiments demonstrating this solution and its properties, for both one and two dimensional examples, are presented. Timing and storage requirements are discussed.

Constrained Solutions to Inverse Source and Scattering Problems

A. J. Devaney
Schlumberger-Doll Research
P. O. Box 307, Ridgefield, CT 06877

The inverse source problem consists of deducing a source term $\rho(\underline{r})$ to the inhomogeneous Helmholtz equation $(\nabla^2 + k^2)\psi(\underline{r}) = -\rho(\underline{r})$ from measurements of the field $\psi(\underline{r})$ performed *outside* a volume τ known to contain the source. The source may either be self-luminous or, as is the case in inverse scattering, ρ can be an induced source, equal to the product of a scattering potential $V(\underline{r})$ with the field ψ. In this paper it is shown that the various commonly employed integral equation formulations of the inverse source problem are all mathematically equivalent and that the class of so-called *nonradiating* sources occur as solutions to the associated homogeneous forms of these integral equations. The ill-posed nature of the inverse source problem caused by nonradiating sources is shown to be correctable by imposing certain auxillary constraints on the sought after solution. Specific constraints considered in the paper include minimum source "energy" [min. $\int d^3r|\rho(\underline{r})|^2$] and minimum source-field "interaction energy" [min. $\int d^3r\,(\rho^*\psi + \rho\psi^*)$]. The constrained solutions to the problem are shown to be readily obtainable from either the radiation pattern of the field ψ, (scattering amplitude in the case of inverse scattering), or in terms of the boundary value of the field and its normal derivative over any closed completely surrounding the source volume τ.

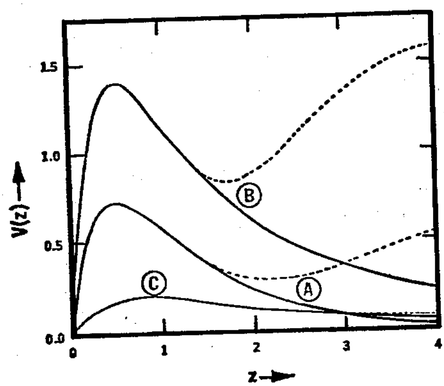
A SCHEME FOR THE NUMERIC RECONSTRUCTION OF DIELECTRIC PROFILES

D.L. Jaggard, H.N. Kritikos and D.B. Ge
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Penna. 19104

Because of its diverse applications, the problem of profile reconstruction by inverse scattering has attracted great interest since the pioneering work of Gel'fand and Levitan, circa 1950. Closed form solutions have appeared for this problem [see e.g., I. Kay, New York Univ. Res. Rpt. No. EM-74 (1955) and A. K. Jordan and S. Ahn, Proc. IEE 126, 945-950 (1979)] but are typically applicable to a limited class of dielectric profiles.

In this report we present a simple numeric scheme for the accurate reconstruction of arbitrary dielectric profiles. The scheme is based on a solution to the Gel'fand Levitan integral equation which is transformed by a change of variables. The resulting equation is discretized and solved by leapfrogging in space and time. In this form the method provides accurate reconstructions for slowly varying monotonic profiles. By a slight alteration involving several iterations, the method can be extended to non-monotonic profiles as demonstrated in the plot below.

Several other cases will also be considered which will exemplify the simplicity and economy of the technique. Of particular note is the fact that this scheme avoids the complexities of matrix inversion.



Potential profile reconstructions V(z) as a function of distance z into the dielectric. The solid lines represent the exact and iterative solution while the dashed lines represent the leapfrogging solution.

ONE DIMENSIONAL HIGH FREQUENCY PROFILE INVERSION

D.L. Jaggard, D.B. Ge and H.N. Kritikos
Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Penna. 19104

The presence of a dielectric and confirmation of its profile shape constitute problems of current interest in remote sensing and inverse scattering. A well known technique for extracting one dimensional profiles from reflection data is based on the solution of an integral equation [I.M. Gel'fand and B.M. Levitan, Izv. Akad. Nauk. SSRser. Math. 15, 309-360 (1951)]. However, closed form solutions are restricted, by tedious algebra and fundamental mathematical limitations, to limited classes of reflection coefficients [see e.g., A.K. Jordan and S. Ahn, Proc. IEE 126, 945-950 (1979) and K.R. Pechenick and J.M. Cohen, Phy. Lett. 82A, 156-160 (1981)].

Here we invoke the physical condition that at high frequencies the reflection coefficient is moderate or small. This allows the linearization of the Riccati equation for the reflection coefficient and a simple expression then approximates the profile from the reflection data.

Results for meromorphic reflection coefficients include the following:

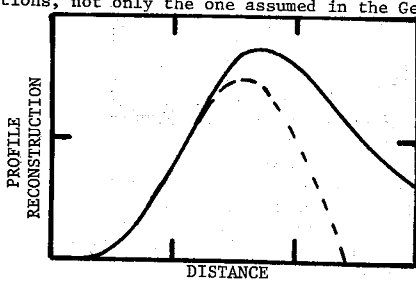
(i) a rule of thumb is found for determining the region of validity for this method;

(ii) an accurate description of the profile shape near the illuminated region of the dielectric is known;

(iii) closed form expressions can be written for profiles characterized by reflection coefficients with an arbitrary number of poles.

The figure below illustrates the method for a profile described by an eight-pole reflection coefficient.

The virtues of this method include the facts that the complexity of this reconstruction scheme is relatively independent of the number of poles and that this scheme can be used for several dispersion relations, not only the one assumed in the Gel'fand Levitan formulation.



Approximate (dashed line) and exact (solid line) profile reconstruction as a function of distance from an eight-pole reflection coefficient.

INVERSION OF SCATTERING DATA FROM UNIFORM DIELECTRIC SPHERES

Egon Marx and George W. Mulholland
National Bureau of Standards
Washington, DC 20234

We determine the radius r and the refractive index n of polystyrene spheres by measuring scattered light from a He-Cd laser as a function of angle and fitting the data to curves obtained from Mie theory. The radius varies from about 150 to 1000 nm, compared to a wavelength of 442 nm. We use a Differential II light scattering photometer, where a single sphere is levitated in an electric field. We assume that we have a monochromatic plane wave that scatters off a homogeneous dielectric sphere.

We minimize the quality of fit Q of the data to a theoretical curve to determine the best values of n and r. The nature of the surface showing Q as a function of n and r provides a visualization of the accuracy of the fitting process. For the smaller radii, Mie curves have no peaks and the Q surface is rather flat with a shallow minimum. For larger radii, a surface may have a trough at an angle to the axes, with a nearly level bottom and steep sides. Thus, errors in the data can change significantly the best values of n and r with little change in Q. For a given n, r can be determined very precisely. Measurements with light polarized either parallel or perpendicular to the scattering plane resolve some of the uncertainties; we use the harmonic mean of the two values of Q as an overall quality of fit.

Actual data analysis shows that the values of the index of refraction fall mainly between 1.61 and 1.66 (the value for bulk polystyrene at this laser frequency is 1.615). Repeated measurements on the same particle show good agreement, although a change in polarization can give rise to larger differences in the results. Sources of noise include the motion of the particle within the laser beam, saturation of the photomultiplier or the voltmeter, and stray light in the instrument. We found that small changes in the angle calibration lead to sizable changes in the best values of n and r. Computer "experiments" in which values obtained from Mie's formulas are changed in a prescribed or "random" manner show the importance of this effect, as well as the smaller effect of the added noise. Impurities deposited on the spheres and inhomogeneities of the polystyrene also affect the scattered intensities.

Noise and measurement errors cause difficulties, and a considerable amount of judgement has to be exercised to select the definition of Q and to resolve discrepancies between different results. Definitions of Q include least squares fits of the data, of the logarithm of the data, and of the data multiplied by a factor of $\sin^2(\theta/2)$. The first tends to emphasize errors in the large intensities at small angles, the second has difficulties with very small values, and the third emphasizes measurements in backward scattering, but gives comparable sizes to different peaks.

AN INVERSE SCATTERING STUDY OF THE DYSON EQUATION FOR RANDOM OCEAN BOTTOM SEDIMENTS:

I. M. Besieris and W. E. Kohler
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

The deterministic inverse scattering results of D. C. Stickler and P. A. Deift ["An Inverse Problem for a Stratified Ocean and Bottom," J. Acoust. Soc. Am. (to appear)] have been adapted to the ordinary differential equation emerging from the Dyson equation for the mean pressure field under the assumption of lossy ocean sediments exhibiting highly anisotropic "pancake-like" statistical fluctuations, in addition to refracting and sound speed profiles.

Motivation for this work has stemmed from the idea that many measurements will probably have to be averaged prior to any application of an inverse scattering algorithm to recover the sediment structure. Thus, if one processes the mean or averaged pressure in the context of a random model, the relevant equation whose properties are being deduced is the equation satisfied by the mean field, i.e., the Dyson equation.

A QUASI REAL TIME MICROWAVE INVERSE SCATTERING TECHNIQUE APPLICABLE TO BIOMEDICAL TOMOGRAPHY †

J. Ch. BOLOMEY, L. JOFRE, G. PERONNET, Ch. PICHOT
A. IZADNEGAHDAR, H. BERKANE, M. SOLAIMANI,*
G. COLLIGNON, Y. MICHEL, J. SAINT, C. SZELES.**
M. GAUTHERIE, J.L. GUERQUIN-KERN.***

* Laboratoire des Signaux et Systèmes
Groupe d'Electromagnétisme
C.N.R.S. - E.S.E.
Plateau du Moulon
91190 GIF-SUR-YVETTE - FRANCE

** Société d'Etude du Radant
Avenue de l'Atlantique
91942 - LES ULIS CEDEX - FRANCE

*** Laboratoire de Thermologie Biomédicale
Faculté de Médecine
Université Louis Pasteur
67085 - STRASBOURG - FRANCE

A new technique for biomedical microwave imaging is presented : its salient advantages are rapidity, low level of radiated power and low cost.

A 15 dBm source applicator is used to illuminate the organ to be tested. Probation of the field scattered by the organ on a surface is achieved through a modulated scattering technique : this allows a very low acquisition time (about 1 ms per point). [J.Ch. BOLOMEY, Invited Communication, Comité espagnol de l'URSI, Barcelone, 1-2 Oct. 1981, p. XI].

The reconstruction algorithm is based upon an angular spectrum method ; only FFT algorithms are needed. With the help of an array processor, time like 1 second per image can be reached.

The surrounding medium is water in which the wavelength at 3 GHz is 1.16 cm. In this configuration slices of the organ in all directions are obtained with a resolution of one half of a wavelength.

These techniques have been applied successfully to homogeneous bodies like plexiglass rods and inhomogeneous ones like cylindrical shell and a pig kidney.

---

† (Contract DGRST n° 81.M.909)

IMPROVED RESPONSE WAVEFORMS FOR THE CIRCULAR DISK

E.M. Kennaugh
D.L. Moffatt
ElectroScience Laboratory
Department of Electrical Engineering
The Ohio State University, Columbus, Ohio 43212

While approximations using the geometrical theory of diffraction generally yield good results at high frequencies, for backscattering by a circular disk these yield non-casual time responses. A time-domain method for correcting this inconsistency and improving the estimation of scattered or induced fields at lower frequencies is described. It is shown that estimation of complex resonance frequencies and the associated kill-pulse for the disk are also improved by this method.

Transient scattered waveforms computed for the circular disk under several illuminating waveforms will be presented to illustrate the use of signal waveform to control the duration and polarization of scattered waves.

FAR FIELD IN TRANSIENT RADIATION AND SCATTERING

N.J. Damaskos, R.T. Brown
NJDI, Box 469, Concordville, PA 19331

and

P.L.E. Uslenghi
University of Illinois at Chicago

A definition of far field for time-domain scattering (or radiation) is given heuristically, by introducing the dimensions of the scatterer and the length of the scattered pulse (which in turn depends on scatterer, incident pulse and direction of observation) as characteristic dimensions. This heuristic definition allows us to simplify considerably the formula which gives the scattered far field as an integral over the sources.

A more precise meaning of the simplifications thus obtained is achieved by Fourier transforming our approximate time-domain results. For example, in the frequency domain in two dimensions with E-polarization, we obtain the far field in terms of an error function; this can be asymptotically evaluated to yield the well known CW far field formula, provided that the length of the scattered pulse is chosen much larger than one quarter of the longest wavelength associated with the bandlimited incident pulse.

What defines far field. (~~Disagree with limit~~). I feel

$$\bar{A} = \int_V \frac{\bar{J}(\bar{r}', t - R/c)}{4\pi R}\, dv' \qquad R = \sqrt{(\bar{r} - \bar{r}')^2} = r\sqrt{1 - 2\frac{\hat{r}\cdot\bar{r}'}{r} + \frac{r'^2}{r^2}}$$

$$\simeq \frac{1}{4\pi r}\int_V \bar{J}\left(\bar{r}', t - \frac{R}{c}\right) dv'$$

$$\frac{R}{c} \sim \frac{r}{c}\left(1 - \frac{\hat{r}\cdot\bar{r}'}{r} + \frac{r'^2}{2r^2} - \frac{1}{8}\left(\frac{\hat{r}\cdot\bar{r}'}{r}\right)^2\right)$$

$$\int_V \bar{J}\left(\bar{r}', t - \frac{r}{c} + \frac{\hat{r}\cdot\bar{r}'}{c}\right) dv', \quad \frac{r'^2}{2cr} \ll \Delta t \text{ of } \boxed{\bar{J}}$$

TIME-DOMAIN TECHNIQUES IN THE SINGULARITY EXPANSION METHOD

W. A. Davis and D. J. Riley
Department of Electrical Engineering
Virginia Polytechnic Institute and
State University
Blacksburg, VA 24061

Cordaro and Davis have suggested a method which transforms the pole searching problem into an algebraic eigenvalue problem. However, this transition necessitates the eigensolution of very large, sparse matrices. The use of simultaneous iteration for the eigensolution of these matrices has made this method feasible for finding the first few layers of poles for one- and two-dimensional problems.

In this contribution, the two-dimensional rectangular plate problem is considered in the time-domain using both triangular and rectangular griding techniques with finite differences. The relative merits of each are discussed, and the first few layers of poles for this problem are also examined.

Wilson – Meas. Results on Rect. Plate

Wilton – F.D. in Time + Δ's.

I. N. – Rect. Plate poles.

THE EFFECT OF PERTURBATIONS OF A SURFACE ON ITS NATURAL FREQUENCIES

R.K.Ritt, Illinois State University, Normal, Il.

Let $H(x,s)$ be the Laplace Transform, for s in the right half plane, of the magnetic field exterior to a bounded piecewise smooth perfect conductor, S, that is produced by an impulsive point source, located at x_o, with polarization p. Let $h(k,s)$ be the Fourier Transform of that function which is $H(x,s)$ exterior to S and zero for x interior to S.

It is shown that

$$(s^2/c^2 + k\cdot k)\cdot h(k,s) + ik/4\pi^2 \times \iiint N(k - k') \times h(k',s)\, d^3k' = ik \times p\, e^{-ik\cdot x_o}$$

where

$$N(u) = 1/4\pi \iint_S n(x)\, e^{-iu\cdot x}\, dS(x),$$

$n(x)$ being the unit normal on S.

$h(k,s)$ is analytic in the right half plane; the integral equation persists for the analytic continuation of $h(k,s)$ into the left half plane, and the singularities of this continuation are the natural frequencies of S.

The effect, of perturbing S by a matrix close to the identity, on the function $N(u)$ is calculated; using this, perturbation formulas for the natural frequencies are derived.

ROOT LOCUS PLOTS OF THE

SINGULARITIES OF THE HELICAL ANTENNA

Thomas H. Shumpert
Thomas A. Blalock
Electrical Engineering
Auburn University, Alabama

Equations for the natural response of a thin-wire antenna in the form of a helix are evaluated. The method of moments is employed in the complex frequency domain to determine the loci of the critical singularities as a function of the pertinent electrical/geometrical parameters - axial length of helix, diameter of helix, diameter of helix conductor, and pitch angle. Plots of these loci are presented, and the relationship between the singularities and the known radiation modes (normal and axial) of the helix are discussed. The subsequent transient response characteristics of the helical antenna are addressed also.

S-PLANE SURFACE FEATURES

FOR SIMPLE THIN-WIRE SCATTERERS

Thomas H. Shumpert
Thomas A. Blalock
Electrical Engineering
Auburn University, Alabama

In recent studies much attention has been devoted to the location and movement of the s-plane singularities of simple thin-wire scattering systems. Root locus plots for isolated bent wires, crossed wires, and parallel and colinear two-wire systems have proven valuable as an aid to understanding the mutual coupling in these systems. Even crude contour plots of the s-plane have been included by some investigators to provide additional insight into these coupling mechanisms. This investigation represents an attempt to utilize three-dimensional plots of the impulse response function for simple scattering systems to effect a qualitative sensitivity analysis as a function of pertinent geometrical parameters. Analytical and numerical schemes for accentuating desired s-plane features and suppressing unwanted features are discussed and examples are presented.

TRANSIENT RESPONSE OF THE PROLATE SPHEROIDAL IMPEDANCE ANTENNA

Joseph D. Kotulski
University of Illinois at Chicago
and
Naval Research Laboratory, Washington, D.C.

A prolate spheroidal impedance antenna is excited at the equatorial gap by a ϕ-independent step voltage. The medium is assumed to be homogeneous and isotropic and the far field is expanded in terms of the spheroidal wavefunctions. The boundary condition at the spheroid is either inductive or capacitive; this excludes the case of active loading of the antenna. The spheroidal wavefunctions are in turn expanded in terms of Legendre polynomials of the first and second kinds. This yields a representation valid in the low frequency region that encompasses the first two resonances of the perfectly conducting spheroid. From the s plane representation, the time response is determined by Laplace inversion.

CYLINDRICAL STRUCTURES RESPONSES TO E.M. PULSES ILLUMINATION.*

B.JECKO & B. PECQUEUX - UER des Sciences -
Laboratoire d'Electronique des Microondes 123 rue A. Thomas
87060 LIMOGES Cedex - France -.

Transient Scattering by perfectly conducting cylinders illuminated by E.M. pulses is solved, directly in time domain, using a new integral equation approach (B. Jecko and A. Papiernik : Int. URSI Symp. on E.M. Waves - Munich, 1980). Magnetic Field (MFIE) and Electric Field (EFIE) integral equations are established and compared for incident waves with TE and TM polarisation. For cylinders with circular cross-section a comparison with thin wire solutions gives a time-domain criterion fo "thin wire approximation" validity.

Firsty, an application to the EMP response of a very long antenna (length L = 300m) above a perfectly conducting ground is presented. The antenna model consists of two parallel cylinders with 2L length and two different radii. For protective elements definition the time evolution ($0 < t < L/c$) of the induced center current is evaluated.

An integral equation for infinitely long straight wires is deduced. From EFIE because of his simple form, this equation can be easely applied to determine the EMP response of many parallel wires. Application to EMP penetration into a circular bulding is presented.

* This work is supported by : Etablissement Technique Central de l'Armement E.T.C.A. (C.A.D.) 94114 ARCUEIL (FRANCE).

ELECTROMAGNETIC PULSE RESPONSE OF A SINGLE APERTURE

SPHERICAL CAVITY WITH LOSSY WALL

Probir K. Bondyopadhyay

Department of Elect.Engg.Tech & Comp.Sc.
New York Institute of Technology
Old Westbury, New York

ABSTRACT

A novel efficient method for analyzing the Electromagnetic Pulse response of a single aperture conducting spherical cavity, containing, in general, a lossy wall is presented. The analysis is based on the spherical transmission line mode representation of the electromagnetic fields both in and outside of the cavity. An integral equation in unknown aperture electric field is solved by the Galerkin's method numerically and very efficiently to obtain the penetrated field at frequencies centered around the resonant frequencies of the cavity. The integral equation is given as (IEEE EMC Digest 1981 pp. 517):

$$\underset{\sim}{H}_o = \sum_{p=1}^{2} \sum_{n=1}^{\infty} \sum_{m=0}^{n} \iint_{apert} R\, \underset{\sim}{E}_t\, \underset{\sim}{e}^*_{pmn}\, d\Omega (Y^{int}_{pn} - Y^{ext}_{pn})\, \underset{\sim}{h}_{pmn}$$

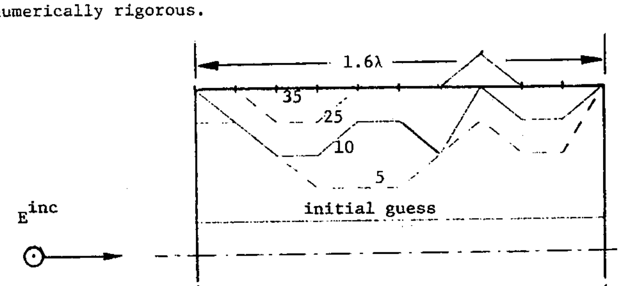
where, the loss in the uniform thin dielectric coating of the wall is incorporated in the internal modal admittances through spherical transmission line impedance relations.

Inverse Fast Fourier Transform techniques are employed to recover the transient response from the computed frequency domain response around the resonant frequencies for various lossy wall conditions. Shifted complex resonance frequencies of the lossy cavity are also obtained from this analysis.

NUMERICALLY RIGOROUS INVERSE SCATTERING USING STACKED 2-D SPECTRAL-ITERATIVE APPROACH

R. Kastner and R. Mittra
University of Illinois
Urbana, Illinois

In this paper, we present a new approach based on the spectral-iterative technique (Kastner and Mittra, 1981 IEEE International Symposium Digest, June 16-19, 1981, pp. 312-314) for solving the inverse scattering problem for a general shaped body. The approach is based on slicing the scatterer by a number of parallel planes over which the current distribution is sampled, and applying an iterative procedure to recover the profile of the body. The process starts with an assumed initial shape and a corresponding initial guess for the current distribution. This assumption is subsequently improved one plane at a time by applying the boundary condition $\underline{E}^{tot}=0$ inside the assumed body, and by augmenting the initial profile of the body with regions where the condition $\underline{E}^{tot}=0$ is satisfied within a given tolerance. Upon completion of one scan of the scatterer, its spectral field due to the currents on the iterated scatterer is modified by replacing its values within the visible range by the known far-field quantities while leaving the values in the unknown, invisible range unchanged. The entire process is then repeated, as needed, until convergence is achieved. Each single scan of the body produces a modified shape and a modified current distribution, and is defined as one cycle of the iteration. The process of progressing between the planes is done efficiently in the spectral domain, where the current-field relationships are of simple algebraic form. Preliminary results obtained for a strip and a rectangular cylinder with E-mode incidence are very promising (see Figure). The only approximation involved is the discretization of the geometry by a rectangular grid. Since the satisfaction of the boundary condition and the agreement of the far-field data are verified in the process of generating the solution, the procedure may be regarded as numerically rigorous.



Convergence of body profile with number of iteration as a parameter.

INVERSE SCATTERING PROBLEMS IN ALMOST PERIODIC MEDIA

D.L. Jaggard† and A.K. Jordan*

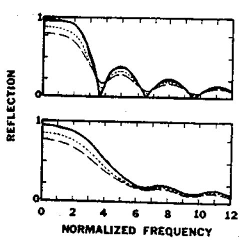
†Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Penna. 19104

*Naval Research Laboratory
Washington, D.C. 20375

In this presentation, we investigate the relation of two areas of mathematical physics, namely, inverse scattering and the theory of almost periodic functions. The discipline of inverse scattering theory has attracted the attention of many researchers since the pioneering work of Gel'fand, Levitan and Marchenko, circa 1950. Their work concerned one-dimensional profile reconstructions from reflection coefficient data. Increased understanding of the problem was gained from the closed-form solutions of profiles corresponding to rational-function reflection coefficients [I. Kay, Comm. Pure Appl. Math. 13, 371 (1960); A.K. Jordan and H.N. Kritikos, IEEE Trans. Ant. Propagat. AP-21, 909, 1973; and A.K. Jordan and S. Ahn, Proc. IEE 126, 945 (1979)]. The theory of almost-periodic functions (i.e., functions with discrete or line spectra) has its origin in the work of mathematicians such as Bohr and Besicovitch during the 1920's and 1930's. The theory has more recently been applied to wave propagation problems [D.L. Jaggard and A.R. Michelson, Appl. Phy. 19, 405 (1979); and D.L. Jaggard and G.T. Warhola, Radio Sci. 16, 467 (1981)].

Here we will investigate the use of rational function reflection coefficients, described by several poles, to model the reflection coefficients of almost-periodic potential functions or refractive indices (see figure below). For purposes of illustration we examine almost-periodic media containing a few tones or spatial frequencies.

The connection between inverse scattering theory and almost-periodic potentials is useful since media with arbitrary spatial variation can be represented by a series of almost-periodic functions.



Typical reflection coefficients, as a function of normalized frequency, for several almost periodic structures with three tones

IDENTIFICATION OF SHIPS USING H.F. RADAR

E. K. Walton and C. H. Yang *
The Ohio State University
ElectroScience Laboratory
Electrical Engineering Department
Columbus, Ohio

An experiment will be discussed in which radar backscatter measurements were made on scale models of ships and the results used to test the performance of the nearest neighbor technique for target classification.

The measurement system used a phasor radar system in which magnitude and phase measurements were made on scale models of the ship targets. The radar system measured the absolute radar backscatter cross section of the target, as well as the phase of the signal with reference to a predefined position in space located near the center of the scale model. Scans in frequency were made over octive bands from 1 to 12 GHZ. This measurement system will be briefly described.

The models consisted of 1:1000, 1:1200 and 1:2400 scale models ranging from simple (canonical) models to fairly detailed models of specific modern naval ships.

The nearest neighbor technique was applied to groups of 3 or 4 of the model measurements, and the performance of this technique for target classification was studied. Influences such as noise, available frequency coverage, inclusion of the phase data, and small structural changes in the target ship will be discussed.

* C. H. Yang is on leave from:
Shanghai Jiao-Tong University
Shanghai
The People's Republic of China

A Pattern Recognition Approach For Recognizing Aircraft from Radar Returns

Sheldon S. Sandler
Department of Electrical Engineering
Northeastern University
Boston, Massachusetts 02115

The problem of identifying or classifying aircraft from radar returns, forms the basis for the present work. The unique approach of this work is in the direction of solving the problem in toto by means of pictorial pattern recognition techniques. A simple statement of the problem is this: given a limited amount of radar backscatter data from a moving aircraft, what can be said about the geometry of the target? Data consists of microwave backscatter returns from a metallic aircraft. Variables in the radar system are frequency, polarization, differential phase shift, and viewing angle. Since the electromagnetic scattering is only sampled in one direction (for a limited range of angles) and the other system variables are also known over a restricted range, deterministic recognition approaches do not seem applicable. The approach considered here is to use what information is available in the best possible way.

From simple models for an aircraft, data is gathered for presenting the radar backscatter as a function of the variables in the system. Two dimensional gray scale pictures are then constructed based on this data set. As an example, one presentation would have viewing angle as the absissa, frequency as the ordinate, and a black to white intensity for each point proportional to the backscattered signal. This presentation of picture contains patterns which change as a function of the geometry of the aircraft. Based on these characteristic patterns, computer algorithms are devised which identify or classify the aircraft.

Basic to the problem is to say what geometrical parameters are being classified. Our approach is to characterize the aircraft by giving the metrics of the structure. These metrics would be, for example, the length and width of the fusalage and the length and width of the wings. Model studies used for this metric determination would be a finite length cylinder for the fusalage and a flat or elliptically shaped wing. Based on this simple model, pictures were produced for a range of the geometric parameters (i.e. airplane types). Work on pattern recognition and classification algorithm was also begun. Simple automatic pattern recognition algorithms were developed which were able to classify an aircraft. These algorithms computed the metrics of the aircraft from a limited range of the radar pictures and then compared them to a look up table for the actual aircraft.

ANALYSIS OF OPTIMAL POLARIZATION PROPERTIES OF SPHEROIDAL TARGETS AS FUNCTIONS OF ASPECT AND FREQUENCY

Wolfgang-M. Boerner, Sasan S. Saatchi,
Marat Davidovitz, and Gerald Nespor
Communications Laboratory
Information Engineering Department
University of Illinois at Chicago Circle
P. O. Box 4348
Chicago, Illinois 60680

Basic theories of optimal polarization null properties for simple targets are reviewed for the purpose of analyzing the polarimetric behavior of prolate and oblate spheroidal, perfectly conducting scatterers as functions of aspect and frequency.

The moduli of the power scattering matrix elements (σ_{HH}, σ_{VV}, and σ_{HV}), the relative phases of the scattering matrix elements ($\alpha_{HH} - \alpha_{HV}$, $\alpha_{VV} - \alpha_{HV}$, $\alpha_{HH} - \alpha_{VV}$), the loci of the COPOL and XPOL null locations on the Huynen polarization map, and the spherical angle between the two COPOL nulls are plotted. A succinct interpretation of the graphical results is presented showing that polarization control applied to radar target classification represents an indispensable tool.

A HF INVERSE SCATTERING MODEL FOR RECOVERING THE SPECULAR POINT CURVATURE OF A SMOOTH CONVEX, PERFECTLY CONDUCTING CLOSED SHAPE USING POLARIMETRIC SCATTERING MATRIX DATA

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

Bing-Yuen Foo and Wolfgang-M. Boerner
Communications Laboratory
Information Engineering Department
University of Illinois at Chicago Circle
P. O. Box 4348
Chicago, Illinois 60680

The information content of the complete scattering matrix at relatively (compared to scatterer dimension) small wavelengths has been analyzed. In particular, based on the time-domain first order correction to the physical optics currents a relationship between the phase factors of the scattering matrix elements and the principal curvature at the specular point is established.

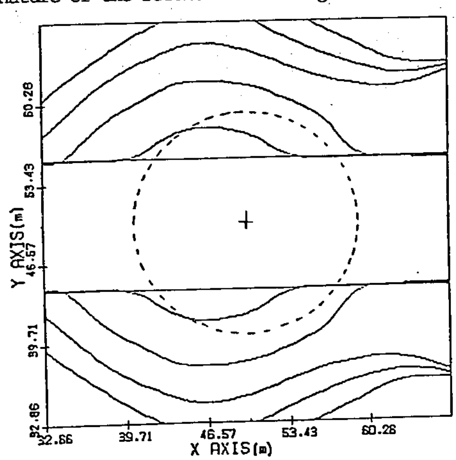
The above phase-curvature relationship is tested by applying it to theoretical as well as experimental backscattering data, obtained from a prolate spheroidal scatterer. The results of these tests not only determine the acceptability of the phase-curvature relationship, it also points out the range of frequency over which the first order correction to the physical optics current is valid.

A NEW ELECTROMAGNETIC INVERSION TECHNIQUE

A. Q. Howard, Jr.
University of Arizona, Tucson, AZ 85721

We describe a volume eddy current technique of reconstruction (VECTOR). The concept of the method is quite straight forward and accounts for the physical process by which energy is first coupled to anomalies in the earth and in turn re-radiated. Measurements of this process are taken along a set of borehole-locations. The modeling is two dimensional. Inversion of field data is simulated with a forward problem which is taken to the lossy, right circular cylinder is a homogeneous lossy infinite medium. The source of excitation is a time harmonic array of uniform electric line sources which are assumed to be non-insulated. They too are assumed to be in a vertical "transmit" borehole. The reconstructed data is displayed as contour plots in the section of the vertical plane between the transmit and receive boreholes. The simultaneous linear equations for the discretized unknown eddy currents are obtained from a volume-current integral equation. The system is inverted using ridge regression.

We have tested VECTOR using simulated field data supplied by computer generated scattering from a right circular cylinder in a lossy medium. A contour phase plot from VECTOR is given in Figure 1 is a reconstructed image of an anomaly having a radius of 10m and located midway between the two boreholes located 100m apart. The frequency is 1 Mhz and the contrast between the anamaly and the background is $100m^{-1}$. The reconstruction used 5 transmitters and 60 receivers. Figure 1 corresponds to a one-dimensional projection (onto the receiver borehole) of the transmitter power. If surface data are included, vertical contour lines should improve the circular nature of the reconstructed image.



CONFORMAL ARRAY DEVELOPMENT ON KC135 AIRCRAFT INCLUDING EFFECTS OF FUSELAGE, WING, AND TAIL DIFFRACTION

E. K. Walton
The Ohio State University
ElectroScience Laboratory
Electrical Engineering Department
Columbus, Ohio

The design of a conformal antenna array on the surface of an aircraft fuselage requires consideration of the effects of scattering and diffraction from the curvature of the fuselage and the wings and tail structures. The beam forming algorithims which can be used for the array in free space will not give the proper distribution of phase (or amplitude) over the array when it is attached to the airframe.

The geometrical theory of diffraction can be used to predict the effects of these scattering and diffraction terms. The far field amplitude and phase from elements located on the fuselage can be computed as a function of element position on the airframe. These data can be used to derive the required array phase distribution for the formation of a particular desired beam.

An example for the KC135 aircraft is given. The phase (and possibly the amplitude) distribution required to generate a beam in a set of given directions will be shown. The beam formed using this proceedure will be compared to the beam formed if a free space algorithm is used.

NUMERICAL ANALYSIS OF A CONFORMAL ARRAY

TIMOTHY R. HOLZHEIMER AND EVERETT A. NELSON
ECI/E-SYSTEMS
P.O. BOX 12248
ST. PETERSBURG, FL

GEORGIA INSTITUTE OF TECHNOLOGY
EES/RAIL
ATLANTA, GA

A numerical analysis has been developed that will calculate the far-field pattern of a conformal array. The method used is similar to (Hsiao and Cha, IEEE AP-22, 81-84, 1974), however, this approach provides greater flexibility. This method is not limited to a conformal array lying on a pure cylindrical surface. It can be used to approximate a cylindrical surface with many planar arrays and each planar array is not dependent on the radius of curvature. It can also be used to generate the far-field pattern of a planar array which can be very useful when the polarization of the elements in the planar array are not all identical. In addition to the relative pattern shape, the absolute gain of the conformal array is calculated. All element positions are calculated in such a way that the element phase calculations are simplified for any array plane tilt angle allowing easy beam scanning calculations. Also, the element pattern is in the form of a complex vector which allows any element polarization to be included in the far-field pattern calculation. Extensive results have been obtained to illustrate the versatility of this numerical code.

MICROSTRIP DIPOLES ON THICK CURVED SUBSTRATES

N.G. Alexopoulos
University of California at Los Angeles

P.L.E. Uslenghi
University of Illinois at Chicago

N.K. Uzunoglu
National Technical University of Athens

Arrays of electric dipoles which are tangent to the outer surface of a dielectric layer backed by a curved metallic surface (modeled by a circular cylinder) are considered. The exact solutions for the field, both inside the coating layer and in the surrounding free space, are expanded asymptotically for a cylinder with diameter large compared to the wavelength and for a thick dielectric layer.

The effects of layer thickness on the self-impedance of each dipole, on the mutual coupling between dipoles and on the radiation pattern of the array are discussed. For small thickness, the results previously obtained for thin substrates by the same authors (National Radio Science Meeting, Los Angeles, June 1981; 5th Antenna Applications Symposium, Monticello, Illinois, September 1981) follow as particular cases.

A THEORETICAL AND EXPERIMENTAL STUDY OF THE "FEED INDUCTANCE" OF A MICROSTRIP ANTENNA

W. F. Richards, J. R. Zinecker, R. D. Clark
Department of Electrical Engineering
University of Houston
Houston, TX 77004

Y. T. Lo
Department of Electrical Engineering
University of Illinois
Urbana, IL 61801

It has been found, both on the basis of experiment and theory, that (excepting the case of degenerate or nearly degenerate modes) the driving point impedance of a thin, microstrip antenna is accurately modeled by a parallel, R-L-C circuit in series with an inductance. Often, this series inductance (which is attributable to the feed and is denoted here as the "feed inductance") is not a particularly interesting or important parameter. However, there are applications in which a correct computation of the inductance associated with the feed, or more importantly with a loaded port of the antenna, is crucial. An example of such an application is in the "frequency agile antenna" (D. H. Schaubert, F. G. Farrar, A. R. Sindoris, and S. T. Hayes, 1980 APS Symposium Digest, p601-604), the resonant frequency of which can be adjusted by varying the locations of one or more shorting pins on the patch. These shorting pins can be diodes, biased open or shorted as required. Other applications utilizing such loaded ports, requiring a knowledge of feed inductances, include the electronic selection of patch antenna polarization and the variation of phase between input and output ports of a series fed array for beam steering.

This paper addresses the problem of accurately computing these feed inductances. The variation of inductance with respect to feed location is quite dramatic, while the simple, position-independent model for the feed inductance (K. R. Carver, 1980 APS Symposium Digest, p617-620) is inadequate for these applications. The physical mechanisms for this variation are presented as well as theoretical computations and measurements. In this paper we will discuss various models for coaxial feeds and their limitations. Numerically efficient methods for these computations will be presented.

AN ANALYSIS OF ANNULAR, ANNULAR SECTOR, AND CIRCULAR SECTOR MICROSTRIP ANTENNAS

J. D. Ou, W. F. Richards
Department of Electrical Engineering
University of Houston
Houston, TX 77004

Y. T. Lo
Department of Electical Engineering
University of Illinois
Urbana, IL 61801

The results of the analysis of an annular (circular ring) antenna, an annular sector, and a circular sector microstrip antenna are presented. These antennas have a number of interesting applications. The latter two approximate triangular and trapazoidal patch antennas and seem naturally suited for mounting on the conical heads of missiles and ogives. The method employed for their analysis was an adaptation of the cavity model (Richards, Lo, Harrison, IEEE Transactions on Antennas and Propagation, January 1981) to these geometries. Several of these antennas were built and tested. The computed input impedances agreed well with these measurements.

ELLIPTICAL MICROSTRIP PATCH ANTENNAS

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

Elliptical microstrip patch antennas of small eccentricities have been studied theoretically and experimentally (Shen, IEEE Trans. AP-29, 68-76, 1981; Long et al., IEEE Trans. AP-29, 95-99, 1981) for circular polarization characteristics. Circular polarization results due to the excitation of nearly degenerate $_eTM_{11}$ and $_oTM_{11}$ modes which are orthogonally polarized. Shen's approximate analysis is applicable to small eccentricity elliptical patches. In this work, elliptical microstrip patch antennas are analyzed using Mathieu and modified Mathieu functions. Patches of different eccentricities are studied experimentally and their characteristics compared to circular and rectangular geometries.

AN EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE RESONANT CYLINDRICAL DIELECTRIC CAVITY ANTENNA

Stuart A. Long and Mark W. McAllister
Department of Electrical Engineering
University of Houston
Houston, Texas 77004

In recent years the frequency range of interest for radiating systems has gradually progressed upward. For several applications today frequencies beyond the usual microwave band and in the millimeter and near millimeter region (100-300 GHz) are required. Many of the antennas that are in current use at microwave frequencies can not be simply scaled up in frequency. Conductor losses become too great for some and for others the excessive reduction in size prohibits economical fabrication. For these reasons new techniques must be developed to radiate energy efficiently at these higher frequencies. In addition new problems arise from the need to integrade the radiators with the desired waveguiding system.

A novel structure which seemingly has the possibility of radiating efficiently and allowing integration with dielectric waveguides is the resonant cylindrical dielectric cavity antenna. Previous dielectric cylinders of very high permittivity (relative dielectric constants of the order of 100-300) have been used as resonant cavities. In each case the emphasis of these investigations has been on the structure as an energy storage device, but since the cavity is not enclosed by metallic walls, electromagnetic fields do exist beyond the geometrical boundary of the cavity. Little or no work has been devoted to this structure as a radiator, nor has a complete investigation of the external fields been made. With the use of lower dielectric constant materials ($5<\varepsilon_r<50$) and proper choices of the dimensions of the cylinder these radiation fields can be enhanced. A first order theory for these external fields has been developed and preliminary measurements have been made on several different dielectric cylinders. This work indicates that such an antenna can be designed to provide reasonably efficient radiation in the direction normal to the ground plane of the antenna. For materials with a dielectric constant greater than about 10, a simple theory utilizing magnetic wall boundary conditions has been developed. Using this theory the resonant frequencies and radiation fields can be calculated. Experimental input impedance data and radiation patterns were then measured and compared with the theory.

THE SIGNIFICANCE OF CROSS-POLARIZATION REFLECTION FROM TRANSMISSION POLARIZERS

David G. Burks
Antenna Laboratory
Texas Instruments Incorporated
Dallas, Texas 75266

Transmission polarizers are two-port devices that are placed between an antenna and the space into which it operates. They are intended to make the polarization of the transmitted field different from the incident field. In addition to being sensitive to the incident polarization, the electrical properties of such polarizers are dependent on the incident angle, so the polarizer is most useful for incident waves confined to a small range of incident angles, such as with electrically large antennas.

Transmission polarizers are typically realized with periodic metal circuits that are etched on thin circuit boards that are separated by low dielectric spacers. Common configurations include ribbon grid, meandering line, Lerner. The thin etched layers are analyzed as lumped elements that shunt a transmission line.

A polarizer for converting linear to circular polarization is obtained by a device having 90° of differential insertion phase between the principal polarizer axes. The polarizer is then exicted with the linear incident field at 45° to the principal axes.

Reflection from the polarizer contains components in the direction of the incident field and crossed to it. If the antenna does not absorb the cross-polarized reflection from the polarizer, this component is returned to the polarizer where it is partially transmitted with opposite-sense polarization with respect to the initially transmitted component. This can increase the axial ratio of the total transmitted field.

The present paper presents an analysis of the effects of this polarizer - antenna interaction on axial ratio and VSWR. The design technique includes compensation for these effects by proper spacing and rotation of the polarizer. The method has been verified with a three-layer meandering-line polarizer that has ultralow axial ratio over a 10% bandwidth.

TAPERED FED MICROSTRIP ANTENNA

C. Kaloi, D. Hatfield
Pacific Missile Test Center
Point Mugu, CA 93042

ABSTRACT

A theoretical and experimental study has been made on a "Tapered Fed Microstrip Antenna" for obtaining improved bandwidth in single microstrip antenna elements. Past investigators have used multi-mode and arraying techniques (including stacking elements) for obtaining improved bandwidth. These techniques have provided limited bandwidth improvements or unstable radiation patterns over the bandwidth.

Improved bandwidth in this antenna system is obtained by using a tapered feed system to provide proper match over a wider band of frequencies. This new feeding technique can provide approximately two times the bandwidth over a normally fed single microstrip element, and maintains a stable radiation pattern over the bandwidth.

This paper reports the experimental portion of the study, and a more comprehensive analytical paper is in preparation for presentation at a later date.

SCALE MODEL AND FULL SCALE MISSLE LIGHTNING TESTING

Dr. Ganshor
Martin Marietta

Abstract

An extensive lightning test program has recently been completed on a major missile program. The testing was performed in two segments. The first segment consisted of testing a one-tenth scale model of a missile to determine probable lightning attach points. The second segment consisted of injecting simulated lightning strikes on a full scale portion of the missile. During testing, several missile response parameters were measured. The distribution of lightning current over the external surface was measured along with coupled voltages to externally mounted antennas. Measurements internal to the vehicle consisted of lightning induced cable shield currents and magnetic field distribution.

Two test waveforms were utilized for the second segment testing. The first was a damped oscillatory waveform with a fast rise time (approximately 300 nanoseconds) to simulate the high rate of change of current in the initial phase of a lightning return stroke. The second was a slower rise time (approximately 3 microseconds) unipolar waveform to simulate the high current long duration portion of a lightning return stroke first peak phase.

Instrumentation consisted of various derivitive sensors for measuring skin current, magnetic fields, cable currents and voltages. A fiber optics data transmission system provided instrumentation isolation from the hostile electromagnetic environment during test. Data waveforms were recorded and processed using transient digitizers and computer processing and storage. Several methods of analysis for the computerized data were evaluated, and are discussed.

This lightning test program is believed to be one of the most unique and extensive ever performed on any vehicle.

"AEHP For Advanced Aircraft"
AFWAL (FIEA/FIESL)

The Atmospheric Electricity Hazards Protection (AEHP) program of the Flight Dynamics Laboratory (AFWAL/FI) is being conducted through the Atmospheric Electricity Hazards Group (FIESL) for base-line investigations and the Advanced Development Branch (FIEA) to develop and demonstrate AEHP for advanced A/C electrical and electronic subsystems/equipments. Lightning characterization has been conducted using a NOAA C-130 during the 1979-81 "thunderstorm seasons." Airborne records have been made of 3-40 km distant lightning, as well as several direct strokes. Ground based records are also available for many events. These experiences indicate that portions of the return stroke current waveform associated with a cloud-ground lightning may have sub-microsecond rise-time high current peak pulses. It is planned to establish a simulation capability for 100 KA 200 nsec rise-time pulses through a fighter A/C. Initial efforts have demonstrated a 1.5 KA 200 nsec rise-time pulse through an F-16 A/C.

Currents/voltages induced in A/C information and power circuits during the A/C lightning/P-static interactions may cause upset/damage to advanced subsystems/equipment. Fiber-optics data links are being investigated as a counter to this threat. The AEHP Advanced Development Program (ADP) will continue development of this and other protection concepts. After specifying design criteria and establishing the design of AEHP for mission critical/flight-safety elements of A/C the hardness achieved will be demonstrated using appropriate atmospheric electricity threat simulation.

AIRCRAFT LIGHTNING STRIKE CHARACTERISTICS

D. W. Clifford
McDonnell Aircraft Company
McDonnell Douglas Corporation
St. Louis, Missouri 63166

ABSTRACT

Because of the weight, cost and performance penalties which can result from overdesigned lightning protection, it is important that the atmospheric electricity threat be accurately characterized so that protection for aircraft can be optimized without compromising flight safety. Lightning design and test specifications for aircraft are based upon lightning discharge parameters measured on the ground during cloud-to-ground discharges. For conservatism, the most severe cloud-to-ground parameters are used in the specifications. Recent measurements imply that the specifications should include very fast risetime values, making then even more severe. An examination of aircraft operational statistics indicates that the involvement of aircraft in low altitude cloud-to-ground flashes may be very rare. Most strikes are reported to occur while aircraft are flying at the freezing level in or around precipitating clouds. Reports of strikes to aircraft flying below a few thousand feet are very rare in the U.S.

The probable characteristics of lightning discharges experienced at the aircraft are discussed and are argued to be quite different from those which would be measured at the ground for natural cloud-to-ground lightning. The projected characterization draws upon intracloud discharge parameters, theroretic1 considerations, the parameters of triggered lightning discharges to wire-trailing rockets, limited in-flight measurements of strikes to aircraft, and, finally, examinations of lightning damage markings on aircraft.

The importance of the altitude issue to the discussion of lightning discharge characteristics is threefold. First, the presence of the aircraft in the cloud in close proximity to charge centers enhances the probability of triggered lightning. Triggered lightning can be argued to have discharge parameters different from those of natural cloud-to-ground strokes. Second, at cloud altitudes, the probability of a strike to the aircraft being a cloud-to-ground flash is reduced since intracloud discharges are more numerous. Intracloud discharges are known to be less energetic than cloud-to-ground discharges. Third, at flight altitudes, the parameters of a cloud-to-ground flash are expected to be much reduced from their values near the ground. High peak current discrete pulses involve the transfer of charge stored on the ionized channel which generally extends from around the freezing level in the cloud to the ground. If the aircraft is at the upper end of the channel, then the charge on the channel will be almost entirely below the aircraft, resulting in reduced return stroke parameters.

It is predicted that the aircraft will always experience a continuing current discharge due to the leader currents feeding through the aircraft. In some cases, low to moderate level discrete pulses (average 2 to 5 kA, worst case 50 to 100 kA) with rise times from a few to several microseconds will be experienced. These predictions compare favorably with the available measurements of direct lightning strikes by instrumented research aircraft and with damage reports to operational aircraft.

SHOCK EXCITATION LIGHTNING TESTS OF FULL SCALE AIRCRAFT

K. Zeisel
McDonnell Aircraft Co.
McDonnell Douglas Corp.
St. Louis, MO 63166

The pulsed current and shock-excitation lightning simulation techniques were used to analytically and experimentally evaluate the response of high impedance differential wire pairs in a controlled geometry laboratory test and in a full-scale fighter aircraft. The program consisted of three major tasks.

1) Conduct both tests under similar conditions on a long aluminum cylinder in the McDonnell Aircraft Company's high-voltage laboratory.

2) Analyze each test condition theoretically and correlate the results with the experimental data.

3) Move the same test equipment to Wright-Patterson Air Force Base (WPAFB), and repeat the tests on the YF-16 fighter aircraft.

The shock-excitation test configuration differs from the pulsed current test configuration by insulating the aircraft from ground and by incorporating an output spark gap between the test article and the ground return system. The spart gap isolates the test article from ground potential so that the structure is first raised to high voltage and then quickly discharged when the spark gap breaks down.

The cylinder tests and analyses demonstrated that capacitive (C dV/dt) coupling is the principal coupling mechanisms for the high impedance interior circuits. Transmission line effects were found to be very important for both test techniques with the induced voltages being approximately an order of magnitude higher for the shock-excitation case. The fast discharge of the shock-excitation technique quickly changes the output impedance of the cylinder/return conductor transmission line from a high impedance to a near short circuit. This transition strongly excites the cylinder transmission line resonances. As the generator charge voltage and output gap length were changed, the induced voltage excited on the interior wires varied as the time rate of change of the cylinder voltage during gap breakdown ($\simeq$ dV/dt).

The analysis of the cylinder test configuration demonstrated that both the pulsed current and shock-excitation test techniques can be modeled as two coupled transmission line circuits with either distributed or lumped components. The analytically predicted transients agreed well with the experimental data.

Limited aircraft tests on the flight control circuits of the YF-16 produced waveforms and scaling relations similar to those of the cylinder. The fast discharge of the shock-excitation technique produced near threat level values of 10^{11} A/s and 10^{12} V/s. Differential induced voltages on the flight control circuits were only a few volts.

FULL-LEVEL LIGHTNING AIRCRAFT SYSTEM HARDENING (FLLASH) FOR ADVANCED COMPOSITE PLATFORMS

J.A. Birken
Naval Air Systems Command
Washington, D.C.

R.F. Wallenberg
D.T. Auckland
Syracuse Research Corporation
Syracuse, New York

The (1965) design of the F-14 fighter initiated major deployment of advanced composite materials for a total aircraft section. The F-18 (1975) design saw 12.1% by weight and 38% by surface area construction from composites combined with digital fly-by-wire control. The Lear FAN 2100 jet is 100% composite. Future aircraft, missiles and helicopters will contain approximately at least 80% composites as evidenced by the Army's All-Composite Airframe Program which is developing an almost all-composite graphite/epoxy and an almost all-composite kevlar helicopter. The significant reduction in electromagnetic protection in fair to non-conducting composite structural materials combined with flight safety dependence on computer control has sparked significant interest in establishing the electromagnetic hardness of composite platforms in lightning and the nuclear EMP. The hardness of frozen composite aircraft designs will be measured and future designs will consider these concerns in the very early design phase. The Navy's Electromagnetic Design and Synthesis (EMDAS) program is implementing early design hardening trade-offs in the HMX, VSTOL and VTXTS procurement program while the Full-Level Lightning Aircraft System Hardening Program (FLLASH) is measuring lightning hardness on the F-14, F-18 aircraft, AIM-9L missile, and a to-be-determined helicopter. These results will then refine EMDAS as well as evaluate the hardness variation of the full-scale aircraft with sections of different non-metallic materials. By considering the protection needs imposed by disciplines other than EMP or lightning (i.e., heat, life cycle, structural integrity, and laser protection), designs satisfying more than one area are being evolved that truly optimize protection/weight penalties.

During FY-82 and FY-83, the Navy F-14 and F-18 aircraft will undergo full level EMP, lightning, SCIT and CW current injection tests. To date both the THREDE[1] and the triangular surface patch modeling[2] have been applied to the F-14 and are currently being applied to the F-18. This paper discusses available results from these efforts with particular emphasis on the significance of:

- Threat rise time variation
- Material type and distribution variation
- Material joint bonding variation
- Comparison with measured results

[1] R.Holland, "Threde: A Free Field EMP Coupling and Scattering Code", IEEE Trans. Nuclear Science, Vol. NS-24, pp 2416-1421, December 1977

[2] S.M. Rao, "Electromagnetic Scattering and Radiation of Arbitrarily-Shaped Surfaces by Triangular Patch Modeling", PH.D. Dissertation, The Unviversity of Mississippi, August 1980

SUPPRESSION OF INTERFERENCE THROUGH GTD DETERMINATION OF OPTIMUM SHIELDING

E. H. Villaseca and R. W. Berchtold
Hughes Aircraft Company
Ground Systems Group
Fullerton, California

The paper describes how the Geometrical Theory of Diffraction technique may be used to study sidelobe radiation suppression by metallic screens. It is demonstrated that there exist a screen height as well as a distance between the screen and the antenna where the ratio of the far field sidelobe radiation with and without the screen is minimized.

An interesting example of shielding optimization is found in the use of metallic fences to shield high gain microwave reflector antennas in satellite communication. The height of the fence and its distance from the antenna can be optimized to provide the maximum shielding.

Effective and inexpensive interference suppression can thus be derived by the strictly analytical method of GTD.

INTERFERENCE COUPLING THROUGH SMALL APERTURES

John M. Hamm and Werner Graf
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

This paper discusses the results of an experimental and analytical investigation of electromagnetic coupling through holes which are small compared to the wavelength of the interfering signals. The goal of the work reported is to develop the necessary analytical and experimental tools to enable the system designer to decide which apertures require treatment, and to quantify or bound the effects of the treatments which are required.

The aperture coupling problem will be discussed first from a theoretical viewpoint. A simple model useful in bounding the effects of coupling through small apertures will be presented. Most of the earlier work on aperture coupling has only limited application because it is usually stipulated that the aperture is located in an infinite conducting plane. In such a case the aperture may be replaced by equivalent electrical and magnetic dipoles which radiate into an infinite halfspace. However, in most realistic applications the aperture is part of a finite size enclosure or cavity, which is often partially filled with circuits or subsystems. The radiation produced by the equivalent dipoles in a partially filled cavity is not predictable as was the case for the infinite (and empty) halfspace.

We have modeled the aperture in an enclosure by an equivalent circuit consisting of lumped impedances. The model has been applied to untreated circular apertures of various sizes, as well as circular apertures treated with wire meshes and apertures of other shapes. The analysis predicts the voltage across the aperture as well as the current induced in a dipole which fills the aperture. Experiments in the laboratory agree well with the simple theory.

To bound the interference coupled through an aperture to circuits inside the enclosure we used the largest loop which could be fitted inside the enclosure. We found that the maximum voltage which could be induced in such a loop is twice the voltage measured across the aperture. Since no actual circuit installed in the same enclosure could have a larger area than the test loop we postulate that twice the aperture voltage is an upper bound of what may be induced in any circuit or subsystem in that enclosure. Similar considerations apply to the case of electric field coupling, which will also be discussed.

ELECTROMAGNETIC COUPLING DUE TO SHIELD DISCONTINUITIES NEAR CONNECTORS

B.DEMOULIN, P. DUVINAGE AND P. DEGAUQUE

Lille University, Electronics Dept.,
59655 Villeneuve d'Ascq Cédex
France

The bundles of cables used in communication systems are usually made with coaxial or bifilar shielded lines with a surrounding outer shield. In terminating each shielded line at a connector, the interior wire is exposed to disturbing fields since the braid is often terminated by a single wire which is connected either to a connector pin or to the outer shield of the cable bundle. This coupling known as "pigtail effect" has been described by C.R. Paul to determine for example the crosstalk between adjacent cables. In this paper we consider the disturbing voltage which can be induced between the wire and the ground reference if a disturbing current flows on the outer shield.

In order to simplify the calculation and the experimentation, a single model has first been chosen. A coaxial cable is situated inside a concentric metal tube. The shield of this cable presents a discontinuity along a given distance and thus the two parts of the shield are connected either directly with one or many "pigtail wires" or with various impedances between the shield and the outer tube. The different types of coupling are exhibited by using disturbing pulses of current which are injected between the shield and the concentric tube.

From the response in time-domain and by changing the rising time of the pulse, the behavior of the connection in the frequency domain is calculated with F.F.T. subroutines for frequencies ranging from few kHz to 30 MHz. It is thus possible to deduce the current and voltage generators equivalent to the pigtail section. A comparison with theoretical results obtained with low-frequency models is given.

C.R. PAUL "Effect of pigtails on crosstalk to braided-shield cables", IEEE EMC Aug. 80.

This work is supported by the Société Nationale des Industries Aérospatiales (SNIAS) undercontract 09364-4448.

TERMINATION OF CABLE SHIELDS

Werner Graf and Edward F. Vance
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

Much has been written in the EMC literature on the problem of "grounding" the shields on shielded twisted pair or shielded single-wire circuits to reduce interference coupled into the internal circuits if a ground loop is formed by the cable shield. This concern arises most often in low frequency applications. On the other hand, in high frequency applications it is usually desirable to ground the shield as often as possible, and in particular at the ends of a shielded cable, to apply a circumferential bond between the cable shield and the equipment case to which the cable is connected. An incompatibility exists if a circuit operating at low frequency is subjected to interference at a high frequency, such as the effects of lightning or nuclear electromagnetic pulse (EMP).

We have developed a topological approach to interference control. The topological model demonstrates that the proper shield termination at any frequency is to close the shield rather than to ground it (or not to ground it). It will be shown that the application of topological shields to low frequency shielding problems will provide more effective protection against ac power frequency interference than the best grounding techniques. The topological approach has the further advantage that the rules for its application are simpler and the same shield system is effective for high frequencies and transients as well as low frequencies. In addition, great improvements in the performance of circuits using shielded twisted pair could be realized if the common-mode rejection capability of shielded twisted pair were more widely utilized. The common practice of grounding one wire ofthe twisted pair allows all of the common-mode interference to be converted into differential-mode interference.

We have performed a number of simple experiments in the laboratory to illustrate these concepts for single-wire shielded (coaxial) cable, and for shielded twisted pair in both balanced and unbalanced configuration. The results of these experiments will be presented. A clear demonstration can be made that although a low frequency cable shield termination, for example pigtails, may be quite satisfactory at the low frequencies, if this circuit is subjected to high frequency interference as low as 1 MHz, the interference coupled into the circuit will be significantly higher than with a topologically correct shield termination.

THE DISCHARGE CURRENT IN THE LIGHTNING RETURN STROKE*

R. L. Gardner
Mission Research Corporation
1400 San Mateo Boulevard, S.E.
Albuquerque, New Mexico 87108

The current in the lightning return stroke has been the object of a number of analytical models of increasing complexity. Bruce and Golde introduced the concept of a velocity of current pulse propagation. Later, Dennis and Pierce introduced the concept of a traveling current wave along the leader channel. In each of these and later papers, however, the current pulse amplitude, pulse shape, and velocity are assumed functions.

In this paper, we develop a nonlinear, nonuniform transmission line model to find the velocity of current pulse propagation, the current amplitude, and current rise time as functions of time and therefore height. The flexibility of a transmission line model allows us to include physical variables in the form of resistance, inductance, capacitance, and conductance per unit length as functions of height and the history of the current flow through a given cross section of the return stroke channel. Only resistance per unit length is treated in a nonlinear fashion here. The remaining variables are assumed constant to reduce the complexity of the model.

The resistance per unit length is determined by the evolution of a complex hydrodynamic model, which calculates physical and electrical parameters of the channel plasma as functions of time and radius for each cross-section of the plasma. The resistance of a unit length of plasma channel is then found by integrating the conductivity over radius. This resistance per unit length is then updated in the transmission line code at each time step. The transmission line solution has as an initial state the sudden closing of a high voltage switch about 100 m from the ground. The evolution of the current and voltage waveforms along the channel then determine the current pulse rise time, the velocity of the current pulse propagation and the current amplitude. Necessary initial conditions for a propagating pulse are also shown.

*Work performed while at Cooperative Institute for Research in Environmental Sciences, Boulder, Colorado.

ELECTROMAGNETIC PULSE EMITTED BY LIGHTNING

- experimental data and mathematical models
- natural and triggered lightning strokes.

by - J. HAMELIN - C. LETEINTURIER -
Centre National d'Etudes des Télécommunications
LANNION (FRANCE)

In this communication we present our work to date, experimental as well as theoretical, on electromagnetic fields emitted by lightning, both natural and triggered.

The National Research Center of Telecommunications (C.N.E.T.) for several years has been working to deepen its understanding of emitted Electro-magnetic pulses by return-strokes and leaders both in the context of the Saint-Privat d'Allier station experiments and more recently by participating in the COPT 81 campaign (Tropical Deep Convection).

For the experimental programm, and for the studies of the strokes, triggered as well as natural which band sensors (150 Hz - 20 MHz) or spectral analysis (60 MHz - 1 GHz), has been used associated with rapid data acquisition systems.

In parallel, theoretical modelling of this emitted field by the return stroke was carried out, taking into account the current wave-form the upward velocity, the ground resistivity and the height of the observation point.

Finally, we present preliminary results of the C.O.P.T. campaign, both wide band and harmonic analysis, on esssentially intra-clouds events.

LIGHTNING ACTIVITY CHARACTERISTICS FROM VHF SPACE-TIME MAPPING

William L. Taylor
National Severe Storms Laboratory
1313 Halley Circle, Norman, OK 73069

A wide band VHF system employing time difference of arrival techniques has provided azimuth and elevation angles to individual sources of electromagnetic impulses radiated from lightning discharge processes. The simultaneously observed directions and times of arrival recorded at two stations separated by several tens of kilometers define the three dimensional location of each source as a function of time. Analysis of data has revealed characteristics of the lightning discharge process from several storms and has allowed us to accurately associate lightning activity with storm reflectivity and internal wind structure obtained from Doppler radar data. Recent results of this work include: (1) the space-time structure of lightning discharges is extremely complex; (2) lightning activity is generally located in close proximity to, but not necessarily within, the high reflectivity regions of storms; (3) the average height of VHF sources is 4-5 km for cloud-to-ground (CG) flashes and 5-6 km for intracloud (IC) flashes, where the temperature is between -5^{o} to $-20^{o}C$; (4) VHF sources for CG's and large IC's seldom exceed 10 km height; (5) a new class of small IC's forming a canopy over the main updraft region of a storm produce almost a continuum of lightning activity centered at 12-13 km height; and (6) lightning activity moves in a broad front through the thunderstorm volume at progression speeds between 2×10^4 and 2×10^5 $m \cdot s^{-1}$.

AIRBORNE MEASUREMENTS OF LIGHTNING-INDUCED CURRENTS

J. Nanowitz
SRI International
Menlo Park, California

INTERPRETATION OF IN FLIGHT LIGHTNING DATA

R. A. Perala
T. H. Rudolph

Electro Magnetic Applications, Inc.
P.O. Box 26263
Denver, Colorado 80226
(303) 989-2744

One of the current topics having a great deal of interest within the lightning community is the interaction of lightning with aircraft. One of the biggest unknowns in this area is the knowledge of the lightning environment at aircraft altitudes.

In order to obtain such data, NASA Langley Research Center has instrumented an F-106 to obtain electromagnetic coupling data during a lightning event. Data for both attached and nearby strokes have been obtained. The data consists of derivatives of the normal electric field and the tangential magnetic field measured on the external aircraft skin.

In this paper, the problem of determining the lightning characteristics from the aircraft data is discussed. That is, the aircraft response is "backed out" of the data such that the incident current or LEMP waveform is inferred. Results are given for both cases, and are consistent with current knowledge of risetimes and channel current.

Laboratory Model of Aircraft-Lightning Interaction and Comparison with In-Flight Lightning Strike Data

C.D. Turner and T.F. Trost
Department of Electrical Engineering
Texas Tech University
Lubbock, Texas

Modeling studies of the interaction of a delta-wing aircraft with direct lightning strikes have been carried out using an approximate scale model of an F-106B. The model, which is 3 feet in length, is subjected to direct injection of fast current pulses supplied by wires, which simulate the lightning channel and are attached at various locations on the model. Measurements are made of the resulting transient electromagnetic fields using time-derivative sensors. Small B-dot and D-dot sensors have been placed on the model in the locations corresponding to their actual locations on the N.A.S.A. F-106B (1). The sensor outputs are digitized with a sampling interval of 50 ps for a total time of 20 ns, which is the clear time of the apparatus. The signal-to-noise ratio, defined as the peak signal divided by the RMS noise, is more than 40 dB. The noise level is reduced by averaging the sensor output from 10 input pulses at each sample time.

The B and D waveforms show the input pulse followed by reflections due to the various parts of the model structure. These reflections die out quickly, typically within 20 ns, and are explained roughly in terms of simple transmission-line arguments. Computer analysis of the measured fields includes Fourier transformation and the computation of transfer functions for the model. The transfer functions show several resonances of moderate Q. These include the half-wavelength resonance of the fuselage and several higher frequency resonances.

Comparisons of these transfer functions with spectral amplitudes computed for in-flight data show good agreement regarding the frequencies of the resonances. However, one in-flight D-dot waveform shows a strong fuselage resonance (8 MHz) which has a larger Q than that apparent in the corresponding transfer function. This is indicative of a lightning channel for this particular in-flight event with a higher impedance than the wires on the model.

The basic technique has the potential for investigating the response of other types of aircraft and studying interior as well as exterior fields.

1. Pitts, Felix L., "Electromagnetic Measurement of Lightning Strikes to Aircraft," AIAA 19th Aerospace Sciences Meeting, St. Louis, MO, January 1981. AIAA 81-0083.

WIND EFFECTS ON CORONA GENERATED RADIO EMISSIONS: R. Vargas-Vila, Strategic Systems Division, GTE Sylvania, 1 Research Drive, Westboro, MA 01581

Measurements of both visual and radio corona have been made in the presence and absence of wind to determine the behavorial relationship between these electromagnetic emissions. These observations were made at pressures corresponding to altitudes of up to 12.7 km and wind velocities up to 30 km per hour.

Corona was produced on a long thin copper wire by a high voltage generated from a 30 kHz RF source. A high flow rate vacuum pump enabled passage of air through the vacuum chamber while still maintaining a vacuum. Air flow was controlled through a valve and monitored by a flow meter. A capacitively coupled probe mounted outside the vacuum chamber allowed monitoring of the RF waveform in the low HF portion of the spectrum.

Observations reveal that the onset of visual and strong radio corona are coincident. Furthermore, weak radio corona preceding strong radio corona was observed beginning at approximately 85% of the onset voltage of visual corona. Wind, at velocities up to 30 km per hour, has no effect on the critical onset voltage gradient at which visual and radio corona occur. However, wind does enhance the intensity of both visual and strong radio corona. Weak radio corona appears to be unaffected by wind.

WIDEBAND MF ATMOSPHERIC RADIO NOISE POLARIZATION MEASUREMENTS: X.A. DeAngelis, K. Marzotto, J.R. Herman, A.A. Giordano, all at Strategic Systems Division, GTE Sylvania, 1 Research Drive, Westboro, MA 01581

Simultaneous wideband measurements of medium frequency (400-500 KHz) radio noise from two antenna types have been made in the southwestern United States. Atmospheric noise pick up from a vertical monopole and a buried crossed dipole was recorded and subsequently computer analyzed. The crossed dipole output was configured to yield both right-hand and left-hand senses of eliptical polarization. Relationships between first-order statistics (average power, amplitude probability distribution and Vd) of the noise from each antenna are presented. In addition the relationships between the two possible senses of the crossed dipole antenna are presented. Examples of typical cross-correlation relationships between antenna outputs also will be shown.

EFFECTS OF NARROWBAND SIGNALS ON MEASURED WIDEBAND MF ATMOSPHERIC RADIO NOISE: J.R. Herman, X.A. DeAngelis, K. Marzotto, and A.A. Giordano, all at Strategic Systems Division, GTE Sylvania, 1 Research Drive, Westboro, MA 01581

Although it is desirable to obtain carrier-free measurements when studying the characteristics of natural noise, this is not always possible in crowded portions of the radio spectrum. During a recent series of wideband noise measurements in the medium frequency band, it was found that the effects of carrier contamination could not be avoided at certain times of the day or when the natural noise level was very low. Analysis of this data indicates that the statistics of atmospheric noise are altered in recognizable ways by the presence of narrowband signals. For example, the V_d is suppressed, the autocorrelation function decay is limited, and the APD takes on characteristic shapes.

MULTIPATH INTERFERENCE AND ITS SUPPRESSION BY SPREAD SPECTRUM SCHEMES

C. P. Tou
Department of Electrical Engineering
Technical University of Nova Scotia
Halifax, Nova Scotia, Canada B3J 2X4

ABSTRACT

This paper discusses the origins of multipath interference and its suppression by spread-spectrum schemes. Multipath propagation can occur under various atmospheric and geographical conditions. For example, it may be due to stratified layers and inhomogenities of the atmosphere and reflections from ground, hills, mountains, buildings, and other obstacles. Multipath can exist between air-to-ground, aircraft-to-aircraft, and satellite-to-satellite links due to reflections from the surface of the earth. In some cases, multipath may be predictable and appropriate measures can be found to avoid their effects, but in most cases they are not predictable, especially, for mobile communications.

The adverse effects of multipath on communication system can be described in terms of selective fading and intersymbol interference. Either one or the other may be predominant depending on propagation environments. Various forms of diversity reception have been employed to combat selective fading and multiple subcarriers each having long symbol waveforms have been used to overcome intersymbol interference.

It has been shown, based on analysis, that spread spectrum schemes are superior to other approaches in combating selective fading and intersymbol interference. In addition, the spread spectrum schemes can provide other valuable features such as noise rejection, message security, selective addressing, and multiple access. The ability of spread spectrum systems to suppress interference depends on the process gain of the system and on the degree of synchronization which can be established by the system.

WEAK SIGNAL DETECTION IN NONGAUSSIAN NOISE:
BACKGROUND AND RECENT RESULTS

A. D. Spaulding, National Telecommunications and Information Administration, Institute for Telecommunication Sciences, Boulder, Colorado, 80303

This paper begins by comparing the performance of the "normally derived" Locally Optimum Bayes Detector (LOBD) with the performance of various ad-hoc non-linear detection schemes. These known results are reviewed and then it is demonstrated that these theoretical results may be misleading due to the assumptions that are commonly used to analytically derive them. For a particular type of broadband impulsive noise, the critical assumptions of vanishingly small signal levels and large number of samples (large time-bandwidth product is that the Central Limit Theorem applies) are removed, the first analytically and the second by computer simulation. The thus derived performance characteristics are then compared, especially as the signal level increases.

The commonly derived LOBD is not, in general, an asympototically Optimum Detection Algorithm (AODA) for non-vanishing signal levels due to neglecting correct bias terms. Also as the sample size increases (in order to assure the required small probabilities of error), the higher order terms in the expansion of the likelihood ratio can not be automatically neglected. The detector structures which are both LOBD and AODA take different forms than the commonly used LOBD, and the performance of these detectors is compared with the "normal" LOBD and the various ad-hoc non-linearities.

RECEPTION OF TV SIGNALS IN NOISY ENVIRONMENTS

K. M. Wong and D. N. Swingler
McMaster University
Hamilton, Ontario, Canada

PROBABILITY DISTRIBUTION OF AIRBORNE RADAR CLUTTER OF COMPOSITE TERRAIN*

Jen King Jao, MIT Lincoln Laboratory
244 Wood Street, Lexington, MA 02173

ABSTRACT

A novel class of probability distributions resulting from a compound Poisson process is found to correlate well with that of the airborne radar returns from composite terrain. This distribution, derived from the assumptions of random scattering phase and Poisson spatial distribution of the scattering source (D. Middleton, IEEE EMC-19, 106-127,1977), is specified by several physical and statistical parameters in its complete generality. They are: 1) the occurrence probability or average spatial density, and 2) the average radar scattering cross section or the probability distribution of each different scatterer, 3) the radar resouition area, and 4) the average background radiation as well as the radar internal noise power.

Numerical results, calculated by using the Fourier-Bessel series expansion of the theoretical distribution, which is the Hankel transform of a characteristic function (J. K. Jao and M. Elbaum, Proc. IEEE, 66, 781-789, 1978), are in excellent agreement with previous airborne radar clutter measurements by Naval research Laboratory (NRL) (J. C. Daley et al., NRL Report 6749, 1968). Two sets of data gathered at grazing angles of 8 and 15 degrees by the NRL four-frequency radar (which operates in P-, L-, C- and X-bands) on 30 January 1967 in Cape May, N.J., have been analyzed. The measured terrain is generally rural in nature, which includes patches of water, marshes, woods, fields, and residential areas.

Our model reproduces successfully several non-Rayleigh terrain clutter characteristics due to the existence of heterogeneous scatterers, their density variation, and their distinctive radar cross sections. One particular type of clutter distributions occurs frequently;it generally has a Rayleigh slope in the low probability region but its high probability tail appears to follow approximately a Weibull distribution. This situation is modeled well by simulating the terrain as composed of a conglomerate of random diffuse and glinty scatterers. Because our model is constructed by using only measurable parameters, it is well suited for applications such as prediction of clutter distribution, regulation of radar false alarm, and estimation of terrain scattering cross section.

*This work was sponsored by the Defense Advanced Research Projects Agency.

ON THE CHARACTERIZATION AND MODELING OF ELECTROMAGNETIC INTERFERENCE BETWEEN OVERHEAD POWER TRANSMISSION LINES AND RAILROAD COMMUNICATIONS AND SIGNALLING SYSTEMS

K. Umashankar and A. Taflove
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

Many restraints have been placed on the co-location or sharing of existing railroad rights-of-way with new ac power transmission lines, since railroad systems usually have integral communications and signal facilities that can be interfered by an overhead electric power line. This has called for proper characterization, modeling, and mitigation of the electromagnetic interference between overhead power transmission lines and railroad communications and signal systems to assure compatible, normal operation.

This paper describes coupling models which have been developed both for parallel and nonparallel rights-of-way to predict analytically common-mode and differential-mode induced voltages and currents along sections of the railroad track and the associated communication lines. The method is based upon a coupled multiconductor transmission line approach taking into account interactions of the rails with the power lines, nearby ground return, and interaction of the rails by mutual induction and through the ballast. Two different models have been developed to predict interference: one for coupling during normal operation; and the other for coupling during fault current situations. Simple Thevenins type equivalent circuits are obtained for the coupling models which are suitable for treating non-parallel rights-of-way.

Representive results are presented showing the electromagnetic interference and coupling in a typical experimental right-of-way. Field test results of the induced railroad currents and voltages are also presented.

ABSTRACT

Performance Improvement with Soft Clipping in Impulsive Noise

David F. Freeman

We present calculations of the theoretical performance improvement obtainable with soft clipping in an impulsive environment, in the limit of large time-bandwidth signals (e.g., spread spectrum). Our model for impulsive noise is truncated Hall noise. We present performance results as a function of a clipping threshold set to clip signal plus noise some specified fraction of the time. By proper choice of threshold, we are able to obtain nearly optimum performance in impulsive noise, while not clipping a large class of interfering signals.

GROUND-BASED REMOTE SENSING OF TEMPERATURE PROFILES BY COMBINED MICROWAVE RADIOMETRY AND RADAR

E. R. Westwater, M. T. Decker, A. Zachs
Wave Propagation Laboratory
NOAA/ERL, Boulder, CO 80303
and
K. S. Gage
Aeronomy Laboratory
NOAA/ERL, Boulder, CO 80303

Research over the past several years has shown that ground-based microwave radiometers can measure atmospheric temperature profiles from the surface to about 500 mb, under both clear and cloudy conditions. Above 500 mb, retrievals are limited in accuracy because of exponentially decaying weighting functions. Recently, it has been shown (Westwater and Grody, J. Appl. Meteor., 19, 1438-1444, 1980) that knowledge of tropopause height can improve the accuracy of the temperature profile retrieval by as much as 1.0 K rms. In addition, using a six-meter wavelength VHF radar, Gage and Green (Science, 203, 1238-1239, 1979) have shown that it is possible to detect and to measure routinely the height of the tropopause.

Here, we present data obtained during a three-week period in March 1981, in which radar measurements of tropopause height, ground-based microwave radiometric measurements, and NWS radiosonde observations are all simultaneously available. Our analysis of these data (a) confirms the ability of the radar to measure tropopause height and (b) demonstrates that significant improvement in temperature profile retrieval accuracy can be achieved by combining the radar and the radiometric data.

TROPOSPHERIC WIND MEASUREMENTS WITH DOPPLER RADAR

R. G. Strauch, K. B. Earnshaw, K. P. Moran
Wave Propagation Laboratory
NOAA/ERL/R45x4
Boulder, CO 80303

Radio-wavelength Doppler radars are able to measure tropospheric winds in nearly all type of weather. The Wave Propagation Laboratory is currently using several radars to measure vertical profiles of the horizontal wind as part of a program to improve local weather forecasting. In addition, the program goals include the development of a remote wind measurement capability for eventual use in operational meteorology.

Unique features and capabilities of these radars will be described and examples of the data they produce will be presented. A comparison of the relative merits of different wavelength radars will be given.

A RADIOMETRIC EXPERIMENT AT THE BOULDER ATMOSPERIC OBSERVATORY

Piero Ciotti, Agnès Silbermann and Domenico Solimini
Istituto di Elettronica, Università di Roma
Via Eudossiana 18, 00184 Rome, Italy
and
E.R. Westwater
NOAA/ERL/ Wave Propagation Laboratory
Boulder, CO 80303

Ground-based radiometers extract meteorological data from the thermal radiance emitted by the atmosphere. According to the frequency band of operation, and, consequently, to the shape of the weighting functions, radiometric meteorological measurements can be effectively conducted either on the lower part of the atmosphere (P. Basili and D. Solimini, Radio Sci. 13, 303-311, 1978) or on a global height scale (E.R. Westwater et al., J. Appl. Meteorol., 14, 524-539, 1975; D.C. Hogg, IEEE Trans. on Antennas and Propagation, AP-28, 281-283, 1980). While measurements of the full-height meteorological profiles can be satisfactorily checked against the routine radiosonde synoptic data, the evaluation of the performance of small-scale radiometry requires particular atmospheric truth.

Experiments conducted in the Rome (Italy) area in 1975 and 1977 indicated that a ground-based infrared radiometer apparently responds to the fluctuations of meteorological variables, such as those associated with atmospheric turbulence and internal oscillations (P. Ciotti et al., IEEE Trans. on Geoscience Electronics, GE-17, 68-77, 1979). To confirm the interpretation of these radiometric experimental results, a new experiment has been carried out at the Boulder Atmospheric Observatory (operated by the Wave Propagation Laboratory of the NOAA), where the 300 m instrumented tower and other ground-based sensors provide fully adequate atmospheric truth. On several days of August and September 1981, the atmospheric radiance has been measured by an infrared radiometer at different elevation angles and for various meteorological conditions. The output of the radiometer has been recorded together with the measurements taken by the different sensors at the eight instrumented levels of the tower and at ground. A preliminary statistical analysis of data, conducted mainly on the basis of spectra and co-spectra of the radiometric signal and of meteorological variables is reported.

MEASUREMENT OF AIRCRAFT WAKE VORTICES BY MICROWAVE RADAR

R. B. Chadwick and J. R. Jordan
NOAA/ERL/WPL, R45x6
325 Broadway
Boulder, Colorado 80303

Commercial and private aircraft traffic is projected to double by the 1990's. This doubling must take place with the constraint that very few airports will be built because of the tremendous cost and environmental degradation. The present airports will have to be used more efficiently in that traffic density will have to be increased and aircraft separation reduced. This raises the hazard of one aircraft encountering another aircraft's wake. This problem has been studied in great detail and in the late 1970's an operational Vortex Advisory System (VAS) based on surface anemometers was deployed at selected major airports. This system did not provide a reliable indication of vortex hazard location and has been discontinued.

A remote sensor that provides a direct measurement of the potential hazard in the approach zone of a runway would be a key element in an overall plan to reduce separation between aircraft. Acoustic sounders and lasers have been used in experiment programs to measure vortices, but apparently lack the necessary requirements to be used operationally. Sensitive, specialized microwave radar can detect the vortex system of a large jet by scattering from the refractive-index inhomogeneities generated during the decay of the vortex. A measurement of the Doppler spread gives an indication of the hazard of a particular vortex system.

This presentation gives the result of experiments using an FM-CW clear radar to look at the vortex systems of large jets. The radar was situated at the end of a runway at Denver's Stapleton airport and the results show beyond doubt that microwave radar can detect aircraft wake vortices.

RADIO REFRACTIVE INDEX PROFILING FROM ACOUSTIC SOUNDING

J. ABOUDARHAM AND J.P. MON
CNET/RPE, 38-40 rue du Général Leclerc
92131 ISSY LES MOULINEAUX FRANCE

Microwave propagation on L.O.S. links is governed by the behavior of the radio refractive index in the first hundred meters of of the troposphere. Generally refractivity values are derived from meteorological parameters (temperature, humidity and atmosphere pressure) obtained through in-situ techniques like radiosonde or instrumented tethered balloons. Such measurements are expensive and cannot be performed on a round the clock basis. So they lack time resolution. They actually are better suited for supplementing occasionally the information obtained by other continuously operating systems.

Acoustic sounding appears to be a low cost and very promissing technique for continously recording relevant data :

- First, simple inspection of the conventionnal fac-simile recording gives the height and the width of the temperature inversion layer wich is know to play an important role on microwave propagation ;
- Second, magnetic tape recording of the voltage delivered at the receiver amplifier allows to measure the back-scattering cross-section σ of the thermal inhomogeneities.

From σ , the structure constants for temperature and refractive index fluctuations may be derived.

We carried out such measurements and computed relevant quantities which were compared to refractivity profiles drawn from meteorological data obtained with a tethered balloon.

Godd agreement is achieved.

Furthermore it is shown that the rudimentary sensor output, i.e. the voltage at the receiver, needs not be converted intc classical meteorological variables for providing the required information.

THE EFFECT OF ATMOSPHERIC ANISOTROPY ON THE DELAY POWER SPECTRA AND MULTIPATH SPREAD OF FORWARD SCATTERED SIGNALS

H. M. Ibrahim and R. E. Post
Department of Electrical Engineering
and the Engineering Research Institute
Iowa State University
Ames, Iowa 50011

The shape of the delay power spectra of signals received on scatter communication links plays a very important role in the performance of these links. Bello has shown that the multipath spread is a basic parameter that affects the irreducible BER produced by frequency selective fading. However, Bello's model is based on average isotropic atmospheric conditions. The interpretation of the scattering process in terms of an anisotropic model is a more realistic characterization of the state of the atmosphere.

In this paper, we present a study of the effect of the anisotropy variations on the delay power spectra. A simplified Gaussian-shaped anisotropic scattering model is utilized in characterizing an average anisotropy measure parameter. Data taken from ISU-UW forward scatter RAKE radar system is used in the present study. This system operates over a 406 km path at 940 MHz. The RAKE receiver effectively splits the common volume into time delay shells. The system uses a pseudo-random code modulation of 5 or 10 MHz which provides delay resolutions of 0.2 or 0.1 microseconds. The Doppler spectra of each time delay shell is processed to extract the anisotropy measure variation with height. The resulting anisotropy profile is incorporated in the calculations. The initial results indicate that the shape of the delay power spectrum is highly dependent on the anisotropy measure profile.

Several theoretical anisotropy profiles and their corresponding delay power spectra are shown. It is found that a linear increase of anisotropy with height tends to increase the multipath spread parameter. Calculations of delay power spectra based on experimental data are presented. These results show great variability.

MILLIMETER WAVELENGTH MEASUREMENTS OF SEA ICE

J.P. Hollinger*, M.F. Hartman** and B.E. Troy*
*Aerospace Systems Division, Naval Research Laboratory
**Computer Sciences Corporation

Radiometric measurements of sea ice were made in a series of flights over the Greenland Sea and Arctic Ocean in October-November 1981 using the Naval Research Laboratory RP3-A aircraft. Profile measurements were obtained for incidence angles of 0^o and 53^o at 19.3 H and V (H and V refer to horizontal and vertical linear polarization), 22.3 V, 31.4 H and 37.0 H and V GHz, while imaging measurements were made at 90, and for the first time at, 140 and 220 GHz over a 90^o cross-track field of view. A complete spectrum of ice types was encountered including various forms of new, young, first year, second year and multi-year sea ice. Ground truth is provided by an onboard ice observer, photography, a laser profilometer and an infrared thermometer. Preliminary results on the emissivities of the different ice types versus frequency along with examples of the microwave imagery and corresponding photography will be presented. These new measurements at the highest frequencies extend the potential for determination of the fractional ice coverage, for ice type identification and for the location of the ice edge while still preserving near all-weather capability. Millimeter wavelengths are of particular interest for these applications because their use provides the greatest spatial resolution for a given aperture size while still penetrating the low lying fog and ice clouds which perennially cover the marginal ice zone. This work was sponsored by C.A. Luther as part of the Arctic Program of the Office of Naval Research.

THE EFFECT OF A THIN CONDUCTING SHEET ON THE FIELDS OF A BURIED MAGNETIC DIPOLE

D. A. Hill, NTIA/ITS
U.S. Department of Commerce
Boulder, Colorado 80303

The subject of transmitting from a buried vertical magnetic dipole or small loop to the surface has been thoroughly studied with respect to mine communication and miner location (J.R. Wait, Proc. IEEE, 59, 1033-1035, 1971). Complications such as earth layering and loop size and shape (J.R. Wait and D.A. Hill, Radio Science, 15, 903-912, 1980) have also been analyzed. A recent attempt to infer earth conductivity from multi-frequency transmission at a large number of coal mines has indicated that a homogeneous half space is not a good earth model. When a homogeneous half-space model is used to interpret the transmission data, the apparent earth conductivity generally increases with both depth and frequency. In order to provide a better fit with transmission data, we consider a model which consists of a highly conducting thin sheet located over a homogeneous conducting half space. Although this model was selected primarily because it appears to fit the measured transmission data, it has some further justification from earlier conductivity measurements at coal mines which indicate an increased conductivity near the surface.

The source is a vertical magnetic dipole, and the fields in air and in the earth can be written as Sommerfeld integrals. The coefficients are determined by requiring that the tangential electric field is continuous and the tangential magnetic field is discontinuous by the amount of longitudinal current per unit length carried by the thin sheet. Curves of the vertical magnetic field at the surface are generated by numerical evaluation of the Sommerfeld integral. Theoretical results are shown to agree fairly well with experimental data taken for various depths at four frequencies from 630 Hz to 3030 Hz.

GENERATION OF VERTICAL MAGNETIC NOISE BY LATERALLY INHOMOGENEOUS EARTH MODELS

D. A. Hill, NTIA/ITS
U. S. Department of Commerce
Boulder, Colorado 80303
and
J. R. Wait, Dept. of Electrical Engineering
University of Arizona
Tucson, Arizona 85721

Recent studies indicate that the vertical component of magnetic noise is the interfering component in mine communication systems that employ vertical axis loop antennas. Past measurements of atmospheric noise have concentrated on the vertical electric field and the horizontal magnetic field. Lateral variations in earth conductivity can convert horizontal magnetic noise to vertical magnetic noise. This can be a factor in degrading through-the-earth communication and geophysical probing that detect vertical magnetic fields. Here we analyze the response of three laterally inhomogeneous earth models to a horizontal magnetic field excitation. The three models are (1) a rough surface, (2) a laterally varying thin sheet, and (3) a buried circular cylinder.

The rough surface model is analyzed by perturbation, and the scattered vertical magnetic field is found to be proportional to the surface slope. A simple expression is obtained for the first-order vertical magnetic field both in air and in the earth. The field in the earth is relevant to downlink communication.

Both the thin sheet and the cylinder are located at arbitrary depths and are examples of volume scatterers. The conductivity of the thin sheet is taken to vary sinusoidally in the horizontal direction, and a modal expansion is obtained for the scattered field. The coefficients of the expansion are given by an infinite continued fraction which converges rapidly. The scattered vertical magnetic field is maximum at the sheet depth and decays above and below. The buried cylinder is an example of a man-made scatterer such as a pipe, wire, rail, etc. It has finite conductivity, and the axial current is found by applying an impedance condition at the edge of the cylinder. The scattered magnetic field is large near the cylinder but decays rapidly with distance. In addition to the vertical magnetic field, numerical results are given for the surface impedance which is frequently used in geophysical prospecting.

ELECTROMAGNETIC RESPONSE OF A MEDIUM LOADED WITH COATED CONDUCTIVE PARTICLES

by

James R. Wait
University of Arizona
Tucson, AZ 85721

Abstract : We consider a model of a mineralized ore zone in the form of a dissemination of metal particles of spheroidal shape. To account for electrochemical effects, the surface of the particles exhibits an interface impedance that can be any specified function of frequency. A quasi-static analysis is used which is justified because the particles are electrically small Explicit expressions for the induced dipole are given for the prolate spheroidal geometry and the oblate case follows a simple transformation. The result is exact only for the case where the angular dependance of the interface impedance has a special form. A general expression is given for the transientresponse of the particles when the primary field is abruptly terminated. The resulting decay of the secondary field is shown to be a strong function of the particle shape.

Contribution from the GeoElectromagnetics Group, Departments of Electrical Engineering and Geosciences.

11 Jan 82

EFFECT OF ADVERSE SAND STORMS ON MILLIMETER ELECTROMAGNETIC WAVE PROPAGATION

S.C.Gupta and A.Srinivasan
Dept. of Electronics & Communication Engg.
U.O.R.,ROORKEE.

Abstract:- Scattering and Absorption of Electromagnetic energy (E.M.) at millimeter wavelength results in a loss of E.M.Energy and it is estimated theoretically. A laboratory model is developed to simulate the actual sand - storm conditions, to study these effects. The concentration of sand and dust particles vary between 1.0 gm/cm^3 in storms and the size of dust particles vary between 0.015 cm and 0.008 cm. An extended integral equation method and numerical solutions are used for nonspherical sand particles, having a complex dielectric constant. This extended boundary condition method is used to estimate the Scattering Cross- Section of sand particles of arbitrary size and shape and further loss of electromagnetic energy at millimeter waves is estimated and the results are compared with the available earlier results. DEC 2050 computer is used for solving the equations. An open cavity resonators are designed (18 GHz, 30 GHz, 40 GHz, 50 GHz) and various experiments are performed in different simulated conditions. The experimental results are compared with the theoretically estimated results using extended Boundary condition approach. Further recording of loss of electromagnetic signal at 11 GHz microwave link is done in presence of severe- sand storm conditions. The optical visibility was reduced to 100 meters for very short durations. The variation in received signal level of 15 dB for 10 to 15 minutes are recorded.

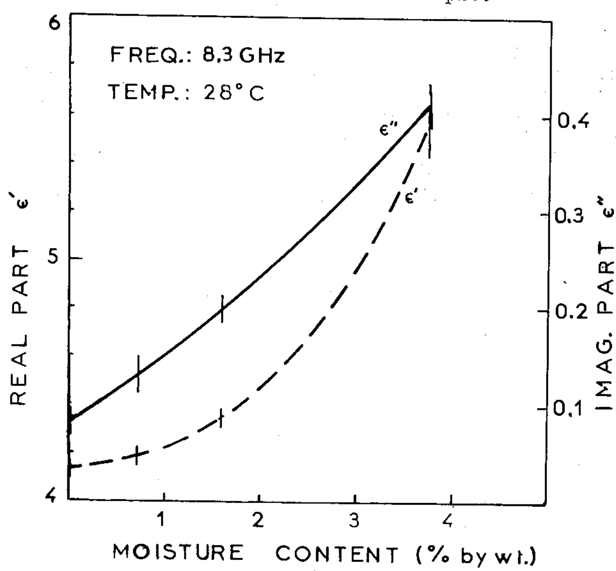
MEASUREMENTS OF THE DIELECTRIC CONSTANT OF DUST AT 8.3 GHz

S I Ghobrial and S M Sharief
Electrical Engineering Dept.
University of Khartoum
Khartoum, Sudan.

Knowledge of the dielectric constant particles suspending or precipitating in the atmosphere is of importance in radio communication and radio meteorology. In desert and semi-desert regions dust and sand storms are frequently encountered and it is therefore of interest to investigate the dielectric constant properties of these particles. It is the purpose of this paper to reveal some results that have recently been obtained at 8.3 GHz.

Measurements of the dielectric constant of dust at 8.3 GHz was carried using a cavity technique. Four dust samples were used and an average value of 4.05±.08 for the real part of the permittivity was obtained. An average value of .084±.015 for the imaginary part was observed.

Investigations of the effect of hygroscopic water on the permittivity revealed that both real and imaginary parts increase with increasing water content. The figure below shows the variation of the real part ϵ' ant the imaginary part ϵ'' with water content for one sample.



HIGH FREQUENCY SCATTERING FROM ARBITRARILY ORIENTED DIELECTRIC DISKS

D. M. Le Vine and R. Meneghini
Goddard Space Flight Center
Greenbelt, Maryland

R. Lang and S. Seker
Department of Electrical Engineering
George Washington University
Washington, DC

Calculations have been made of the scattering amplitude and radar cross section of dielectric disks of arbitrary shape and orientation. A procedure analagous to the Kirchoff approximation employed in physical optics has been used. In this approach, the fields inside the disk are approximated by the fields inside an identically oriented slab (i.e. infinite parallel planes) with the same dielectric properties. These fields excite currents within the slab (conduction and polarization currents) which are the sources of the scattered radiation. The scattered fields are obtained from the induced sources by integrating over the volume of the disk. This computation has been executed here for arbitrary orientation and for observers in the far field of the disk. A dyadic scattering amplitude for the disk has been obtained and specific applications have been made to scattering from vegetation.

The results have been shown to satisfy energy conservation for disks whose diameter is large compared to wavelength. At normal incidence, one obtains the expected result, $\sigma = R^2\sigma_\infty$ for the radar cross section of the disk where σ_∞ is the radar cross section of a perfectly conducting disk with the same shape and R is the reflection coefficient of a slab of the same thickness and dielectric constants (Radar Cross Section Handbook, pg. 522, Vol. 2, Ruck, et. al., 1970). Also as expected, no depolarization occurs if the normal to the disk, the direction of propagation of the incident wave and the direction of propagation of scattered waves are coplanar. (Otherwise, the scattered fields can be depolarized). One expects the results to be valid for disks whose diameter is large compared to wavelength and whose thickness is small compared to diameter, but the thickness need not be small compared to wavelength.

Examples of scattering amplitude, radar cross section, and albedo will be presented for disks with dielectric properties apropos of leaves.

SCATTERING CROSS SECTIONS FOR COMPOSITE SURFACES WITH LARGE MEAN SQUARE SLOPES--FULL WAVE ANALYSIS

Ezekiel Bahar
Electrical Engineering Department
University of Nebraska, Lincoln, Nebraska--68588

Physical optics and perturbation theories have been applied to problems of scattering of electromagnetic waves from rough surfaces. However, these theories can only be applied to a limited class of rough surfaces. Thus perturbation theory can be applied to problems in which it is usually assumed that

$$k_o^2 \langle h^2 \rangle \ll 1, \quad |\partial h/\partial x| = |h_x| \ll 1, \quad |\partial h/\partial z| = |h_z| \ll 1$$

in which $\langle h^2 \rangle$ is the mean square of the rough surface height and k_o is the wave number of the electromagnetic wave. Physical optics, which is based on the Kirchhoff approximations of the surface fields is applicable to surface for which the radii of curvature of the rough surfaces are large compared to the electromagnetic wavelength λ.

The above theories have been applied to composite surfaces made up of irregularities that are both small as well as large compared to the wavelength λ. Using the perturbed-physical optics approach it is necessary to specify the wavenumber k_d where spectral splitting is assumed to occur.

In the composite models [Wright, IEEE Trans. AP-16, 217-223] which are "mostly based on physical considerations" the rough surface is approximated by "patches" of slightly rough surfaces that ride the large waves. Thus the scattering cross section associated with the surface with the small scale roughness is obtained by averaging over the distribution of slopes of the large scale surface roughness.

In this work the full wave approach to rough surface scattering is extended to composite models of the rough surface with large mean square slopes. Since the full wave approach accounts for both specular point scattering as well as Bragg scattering in a self-consistent manner without introducing perturbation and physical optics theories, it is not necessary to decompose the rough surface into two surfaces with large and small roughness scales, h_ℓ and h_s respectively. Thus the need to specify k_d, the wavenumber where spectral splitting is assumed to occur, does not necessarily arise when the full wave approach is used.

It is shown that the total scattering cross section can be written as a weighted sum of individual cross sections. The cross section associated with specular point scattering is multiplied by $|\chi^s|^2$ the magnitude squared of the characteristic function for the small scale surface height h_s. The cross section associated with Bragg scattering is expressed in terms of an integral over the slopes of the rough surface as predicted on the basis of physical considerations. The integrand in this term is proportional to the surface height spectral density function $W(v_{\bar{x}},v_{\bar{z}})$ whose arguments are the two components $v_{\bar{x}}$ and $v_{\bar{z}}$ of the vector $\bar{v}=k_o(\bar{n}^f-\bar{n}^i)$ in the local tangent plane ($\bar{n}^f$ and $\bar{n}^i$ are unit vectors in the direction of the scattered and incident wave normals). The full wave solution can also be expressed in terms of the rough surface tilts "in" and "perpendicular" to the plane of incidence and thereby compared with earlier results.

A MODEL FOR SATELLITE TO AIRCRAFT SIGNALS OVER THE OCEAN

W. H. Peake
Department of Electrical Engineering
The University of Maine, Orono, ME 04469

A satellite-to-aircraft link over the ocean may include a specularly reflected signal and a diffusely scattered signal as well as the direct path transmission.

These multipath signals, which under certain antenna configurations and link geometries can be larger than the direct path signal, must be taken into account in any communication system design. Here we develop a convenient method for estimating the statistical properties of this multipath signal (in particular the doppler and delay spectra). In addition, it is possible to use the model to construct a representation of the total signals which can be used in system or detector design studies (1).

Since the diffuse component is essentially a forward scatter process, we have used a physical optics approach to calculating the signal scattered by the ocean surface. The scattering cross-section, and thus the diffuse and specular signals, can then be related directly to the surface height and slope distributions (or indirectly to the surface wind speed), and (via the complex dielectric constant) to the surface temperature and salinity.

Because the properties of the sea are rather complex, the statistics of the multipath signal are not derived in closed form. Rather the output of the model for a number of representative link geometries are presented to illustrate the feature of the diffuse signal.

Comparison of the model output with an extensive series of measurements utilizing the ATS-6 satellite is made (2), and shows good agreement between the calculated and measured spectra.

1. J. H. Painter and S. K. Jones, Results on Discrete Time, Decision Directed, Integrated Detection, Estimation and Identification. IEEE Trans. COM-25, 715, 1977.

2. A. D. Thompson et al. Air Traffic Control Experimentation and Evaluation with the NASA ATS-6 Satellite. Vol. V Multipath Channel Characterization Test. Rept. FAA-RD-75-173, V Final Rept. Boeing Com. Aircraft Co. Sept. 1976.

A MODIFICATION OF LIN EMPIRICAL FORMULA FOR THE PREDICTION OF RAIN ATTENUATION

By

J.D. Kanellopoulos

Department of Electrical Engineering

National Technical University of Athens

Athens 147, Greece

ABSTRACT

Above 10 GHZ, rain attenuation becomes one of the most important factors governing system reliability. So far, a number of prediction techniques have been proposed in order to estimate the rain attenuation for a given link (A.P.Barsis and C.A. Samson, IEEE Trans.COM, 24, 462-470,1976; R.K. Crane, IEEE Trans.COM. 28,1717-1733,1980; G.Drufuca, J.Rech.atmosph.Fr.8,399-412,1974). All of them are based on raingauge data and can be classified into two main groups (a) rainfall statistics techniques and (b) the synthetic storm technique. The first group methods make use of the effective path length in order to take into account the spatial inhomogeneity of the rain medium. A common method in this area is the simple empirical formula proposed by Lin (The Bell System Tech.J.,56,1581-1604,1977). This method is applicable only for 5-min rainfall rate data, and its simplicity is a challenge for use in areas where raingauge data are available for other j-min integration times such as 1-min.

Subject of this paper is the development of a simple model using rainfall data taken from New Jersey (W.F. Bodtmann and C.L. Ruthroff, The Bell Syst.Tech. J.,53, 1329-1349, 1974) for various integration times.

The crucial assumption of this technique is that the ratio R5(p%)/Rj(p%) (p% is the exceedance probability) is independent of the specific location and has a universal value at least for many parts in the United States of America. A similar idea has been also used by Bodtmann and Ruthroff (The Bell Syst.Tech.J., 53, 1329-1349, 1974) for the conversion of rain rate distributions in the range 2 sec-120 sec of integration times.

The applicability of this technique has been tested against experimental data taken from the eastern coast of the United States for both terrestrial and earth-space links.

IMPACT OF ATMOSPHERIC PROPAGATION PHENOMENA ON THE OPTIMIZATION OF THE ORBITAL LOCATION OF A COMMUNICATIONS SATELLITE

A.K.Sinha, COMSAT General Corporation, Washington, D.C.

This paper presents an analysis of the impact of the scattering, attenuation and related degradations of an electromagnetic wave signal on the performance of a communications satellite system. For an antenna beam coverage by the satellite of a specified geographical region, the longitudinal location of the satellite in the geosynchronous orbit determines the solid angle subtended by the coverage region on the satellite (and hence the antenna gain), as well as the minimum elevation angle of the satellite-earth propagation path within the coverage region (and hence the maximum path length lying in the earth's atmosphere and the maximum precipitation-induced degradation). In the framework of a simple mathematical model, the inherent tradeoff between the antenna gain and fading losses is studied by means of a few illustrative examples, and numerical results obtained with the help of a computer program based on the model are presented.

It is observed that the optimum satellite location typically corresponds to a longitude about 10° to 40° away from the longitude of the center of the coverage region-the exact optimum longitude and the sensitivity of the system performance with the longitudinal variation of the satellite location depending on the shape and orientation, as well as the climatic condition of the coverage region. These results are particularly pertinent for selecting the optimum orbital locations of the new and future generation communications satellite systems operating on fade-prone frequencies (>10 GHz), and for efficient utilization of the basic resources, namely, the satellite power and the geosynchronous orbit.

A 28-GHz ANTENNA GAIN DEGRADATION EXPERIMENT

K. Lin, C. A. Levis and R. C. Taylor
ElectroScience Laboratory
The Ohio State University
Columbus, Ohio 43210

The COMSTAR D/4 beacon signal was measured continuously with a receiver switched at 30-second intervals between antennas aligned on the same axis. One antenna was a 5-meter (diameter) Cassegrain-fed paraboloid, the other a focal-point fed 0.6 m (diameter) paraboloid mounted in front of the Cassegrainian subreflector. The elevation angle was 26.2°. To allow unattended operation, the antennas were pointed in a fixed direction. Therefore their axis did not always point precisely at the satellite because of its diurnal motion. The rain-rate along the satellite-to-receiver path was monitored with an S-band radar.

The preliminary data analysis shows no gain degradation effects due to turbulence in clear air. Gain variations on the order of 2 dB were observed frequently, but not always, associated with rain and storm events. The time scale of the variations ranges from the resolution limit of the experiment to several hours. Enhancement as well as degradation was observed. The most likely interpretation is refraction due to bulk refractive index variations which bring the signal arrival direction sometimes closer to, sometimes further away from, the antenna axis.

The gain variations are usually associated with an increase in the scintillations observed on both antennas. These scintillation increases are generally well correlated for the two antennas. Similar scintillation increases are also observed sometimes without appreciable gain variations.

These preliminary results are consistent with the premise that angle-of-arrival variations and amplitude scintillations are the dominant effects associated with rain and storm events at 28 GHz for antennas on the order of 5-meter diameter.

ANALYSIS OF 18 MONTHS WORK ON AN 11.6 GHz DUAL POLARIZED SITE DIVERSITY EXPERIMENT EMPLOYING THE SIRIO SPACECRAFT

R. E. Marshall, C. W. Bostian, W. L. Stutzman,
E. A. Manus, P. H. Wiley, and T. Pratt
Satellite Communications Group
Electrical Engineering Department
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

The degradation of earth-space communication links operating above 10 GHz by hydrometeors present in the troposphere is significant enough to warrant the use of site diversity. This was introduced by D. C. Hogg (*Science*, January 1968, Vol. 59, No. 3810, pp. 39-46) as a technique for improving the reliability of systems experiencing hydrometeor attenuation. The topic of improving isolation reliability by employing site diversity for dual polarized systems has received very little attention.

This paper describes an 11.6 GHz dual polarized site diversity experiment with a 7.3 km baseline and an 11 degree elevation angle. A tipping bucket rain gauge and snow gauge is located at each antenna, and an S band range gated meteorological radar observes the main site earth-space path during propagation events.

Data will be presented which include single site and joint rainrate, attenuation, and isolation statistics for the period July 1980 through December 1981. Attenuation diversity gain, isolation diversity gain, faderate statistics, and depolarization rate statistics for the same period will also be presented. A prediction of isolation diversity gain based on the attenuation diversity gain will be compared to measured values. Three dimensional plots of dBz vs range vs time and simultaneous attenuation and isolation plots of selected events will be presented. The effects of antenna residuals and ice on diversity statistics will also be discussed.

PROPAGATION MEASUREMENTS IN AN OPERATIONAL ENVIRONMENT

D. V. Rogers, H.-D. Lin, and R. W. Gruner
COMSAT Laboratories, Clarksburg, Maryland 20871

A dual-polarized receive system designed to collect propagation data at 12 GHz by monitoring an SBS satellite telemetry beacon at the SBS TT&C Earth Station in Clarksburg, Maryland is described. Propagation data to be obtained include statistics of cross-polarization discrimination, relative phase between cross-pol and co-pol signals, and co-polar attenuation. The receive system, implemented by modifying an existing 14/12-GHz prototype terminal, is compatible with the scheduled upgrading of this terminal to operational TT&C status.

Constraints imposed by the operational environment (e.g., need to retain 14-GHz transmit capability of the terminal, requirement for independent TT&C operation) are enumerated. Hardware modifications to be discussed include: design of a retrofit antenna feed providing dual orthogonal receive ports while maintaining the transmit port; provision of dual-channel receive capability by simultaneous operation of the primary and backup LNA/downconverter chains; development of a dual-channel receiver to detect the 70-MHz outputs from the existing terminal; and system control and data acquisition techniques. The performance characteristics of the system will be presented.

THE EFFECT OF MULTIPATH AND SCATTERING UPON THE ARRAY GAIN OF A RADIO CAMERA

Bernard D. Steinberg and Eli Yadin
Valley Forge Research Center
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA
and
Interspec Inc.
Philadelphia, PA

ABSTRACT

A radio camera is an adaptive antenna array system large enough to obtain angular resolving power comparable to common optical systems. Following an adaptive beamforming procedure the beam is open-loop scanned to get the desired images. Multipath and scattering of the energy reradiated from the target induces phase front distortions. A theory has been developed showing that the loss in array gain due to the scattered field can be described by a simple relationship involving only two quantities: the strength S of the scattered field relative to the direct field and a spatial correlation function $\rho(\theta)$ associated with the scattering process. The argument θ is the scanning angle. The array gain is $G(\theta) = G(0)S[1-\rho(\theta)]$.

A series of experiments have been conducted to test the assumptions underlying the development of the theory, which appears to vindicate them. The theory and experiments are described.

WAVES IN ANISOTROPIC AND DIREFRINGENT ARTIFICIAL DIELECTRICS

Michael J. O'Brien
Electromagnetic Sciences Division
Rome Air Development Center
Hanscom AFB, Massachusetts

Y. T. Lo
University of Illinois
Urbana, Illinois

W. F. Richards
University of Houston
Houston, Texas

ABSTRACT

The recent need for light weight multiple beam communication satellite antenna systems has stimulated renewed interest in artificial dielectrics. The particular dielectric studied is comprised of periodically spaced square arrays of thin square metallic obstacles. The major objectives of this study are first, to determine why the lenses previously built with this material failed to perform properly, and second, to design a functional lens if possible. The wave propagation properties of this type of medium are found using a full wave analysis. An equivalent multiport network models the modal conversion at the obstacle plane. An eigenvalue problem is then formulated to determine an effective index of refraction and wave admittance for the periodic structure. These bulk properties are subsequently used to analyze the propagation of a microwave beam incident on a medium. The refraction of a beam through a simple dielectric slab is considered first because one can include the effects of both the multiple internal reflections and the susceptive discontinuities at the boundary surfaces. Then the more practical prism structure was considered, since the prism has two refracting surfaces like the lens. The theoretically predicted results are verified by experiments with good agreement. These preliminary results indicate the possibility of designing a microwave lens which satisfies Abbe's sine condition by taking into account the inherent deliterious properties of this material, namely anisotropy and birefringence.

MAXIMUM ENTROPY ARRAY RESOLUTION OF RADIATING SOURCES*

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

The conventional MEM array method (R. N. McDonough, Geophys., 39, 843-851, 1974) resolves sources in direction by extrapolating the spatial autocorrelation function in a most probable sense and computing the resultant wavenumber spectrum by what is effectively autoregressive all-pole modeling (Burg method).

This MEM resolves two equistrength monochromatic sources in amplitude with essentially zero angular separation (without noise) if their phase difference is 90^{o} and $\approx .65\ \lambda/L$ if their phase difference is zero (λ = wavelength, L=aperture length). With noise the resolution depends on the S/N ratio. Gabriel (W. F. Gabriel, Proc IEEE, 68, 654-666, 1980) indicates a nearly inverse-cube relationship between the angular (i.e., wavenumber) resolution and S/N for two equistrength targets. Luthra and Steinberg show the resolution can be improved 7-15db by subtracting the noise autocorrelation function, obtained from multiple-snapshot data, from the total signal + noise autocorrelation function.

Another MEM method (R. M. Bevensee, IEE Conf. Pub. 195, Part 1, 383-387, 1981) has been applied to the resolution of a two-dimensional distribution of monochromatic radiating sources from far-field data taken in various directions. This method show promise for phase resolution in the inverted problem of a non-collinear array of receivers sampling the field of an angular distribution of remote sources.

The resolution capabilities of this latter MEM method will be compared to those of the conventional method and some conclusions will be drawn about the fundamental limitations on source resolution in terms of relevant parameters.

---

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

APERTURE SYNTHESIS FOR MICROWAVE RADIOMETERS IN SPACE

D. M. Le Vine
Goddard Space Flight Center
Greenbelt, Maryland

Aperture synthesis can be employed in passive measurements from space to provide high resolution microwave radiometers for remote sensing applications. The technique could lead to microwave radiometers in geosynchronous orbit with spatial resolution equivalent to real antennas several hundred meters in diameter. The purpose of this paper is to present the concept and results of research being done at the Goddard Space Flight Center to develop the concept into a practical sensor system.

The theoretical basis for aperture synthesis from space is the Van Cittert - Zernike theorem, a well-known result in optics (e.g. Born and Wolf, 1959) which shows that the intensity of radiation on the surface of an incoherent source is the Fourier transform of the correlation function of the fields measured far from the source. This theorem has been modified in work at the Goddard Space Flight Center to apply to earth viewing radiometers. The problem of viewing a large extended source (the earth) from an observation point not in the far field can be overcome and it is shown that a correlating interferometer in space can map the correlation function to obtain a high resolution image of brightness temperature.

Two approaches, single frequency and multiple frequency synthesis, are possible for obtaining the map of the correlation function. In single frequency aperture synthesis, the baseline of the interferometer is changed by physically moving one of the antennas to different positions in the image plane. In multiple frequency aperture synthesis, the physical baseline between antennas remains fixed but the equivalent baseline is changed by making measurements at different frequencies. Both techniques are equivalent theoretically, although for remote sensing purposes from space the most practicle approach appears to be single frequency synthesis from geosynchronous orbit. Example antenna patterns and potential resolution will be discussed.

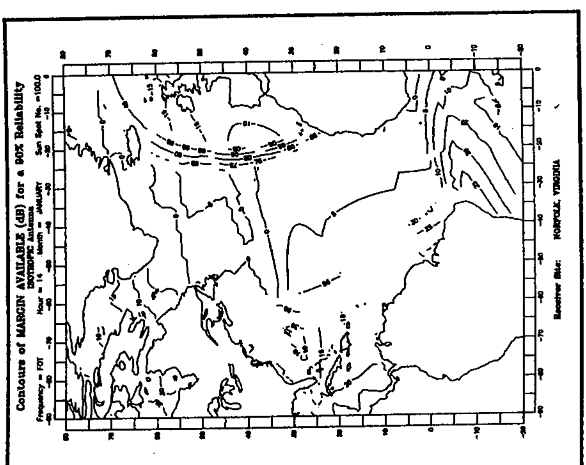
COMPUTER GRAPHICS OF AREA COVERAGE
for
SUBMARINE HIGH FREQUENCY COMMUNICATIONS

J. R. KATAN
and
D. H. S. CHENG

In this study, we investigate the environmental effects, diurnal, solar, and geographical, on the ability of a particular class of submarine antennas to communicate reliably. Calculations are done based on IONCAP which is a comprehensive computer code designed to predict HF sky-wave system performance and analyze ionospheric parameters. A series of computer graphics were developed to reduce myriads of computer data and to assist in the assessment of HF antenna and communication systems onboard a submarine in transit.

The computer graphics provide area coverage displays of key communication and ionospheric parameters. It uses the Cartographic Automatic Mapping program named CAMs which performs a variety of cartographic functions on any one of eighteen map projections. Finally, a program called CONTOUR is included which produces the constant level lines depicting the key parameters.

These techniques are general enough to assist in the understanding of a broad range of problems common to broadcasters, frequency managers, as well as systems analysts.



AUTHOR INDEX

ELECTROMAGNETIC WAVE PROPAGATION IN FORESTS USING A FOUR-LAYERED-MEDIA MODEL AND DYADIC GREEN'S FUNCTIONS*

Gervásio Protásio dos Santos Cavalcante
Universidade Federal do Pará (UFPa)
66000 Belém, PA, Brazil

David Anthony Rogers
North Dakota State University (NDSU)
Fargo, ND 58102, USA

Attilio José Giarola
Universidade Estadual de Campinas (UNICAMP)
13100 Campinas, SP, Brazil

The propagation of radio waves in forests has been the subject of various studies. A typical model that has been commonly used to study this problem has been the replacement of the forest by a homogeneous and isotropic dielectric layer placed over a flat conducting earth. For these analyses Hertz potentials have been used and satisfactory results were obtained (see, for example, D. Dence and T.Tamir, Radio Science, Vol.4, pp.307-318, April 1969).

In the present work a model with four dielectric layers has been considered. Two dielectric layers were used to represent the crown and the trunk of the trees in the forest. These layers were placed over a conducting flat earth. The dyadic Green's functions in their eigenfunction expansion forms were used to analyze this model and the electromagnetic fields were obtained from these functions. The radio losses from 2 to 200 MHz for radiating horizontal and vertical dipoles located in the trunk region and the observation point also located in this region were calculated. The theoretical results agree with the available experimental data for typical forests. For this comparison the parameters of the crown region were estimated for each specific case.

* The present work was performed at the Universidade Estadual de Campinas (UNICAMP), C.P. 1170, 13100 Campinas, SP, Brazil. It has been partially supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Telecomunicações Brasileiras S.A. (TELEBRÁS) and the Coordenação do Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

1983 INTERNATIONAL IEEE APS SYMPOSIUM
USNC/URSI MEETING

MAY 23-26, 1983

at the

UNIVERSITY OF HOUSTON
HOUSTON, TEXAS

For more information write to:

Prof. Stuart A. Long
Department of Electrical Engineering
The University of Houston
Houstong, Texas 76004