1992 JOINT SYMPOSIA

Nuclear EMP Meeting

July 18-25, 1992
Hyatt Regency Chicago
Chicago, Illinois, USA

EM 1992 RECORD

- NEM 94 in Frankr call GRD!
- Gewicht auf höhere Freq.
  $t_r \sim 2-3$ ns!
- TEM Cell up to 1 GHz
  . to resolve many coupl.
  functions (Antennas)

B. Brändli

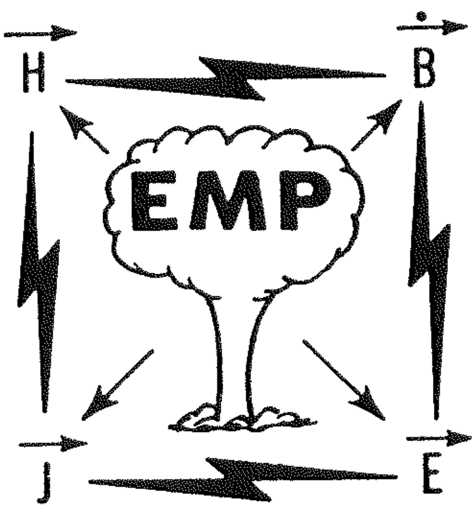
506 Fied

NEM 1992 RECORD

Program and Digest

Nuclear EMP Meeting

July 20-24, 1992
Chicago, Illinois, USA



In conjunction with:
IEEE-APS International Symposium
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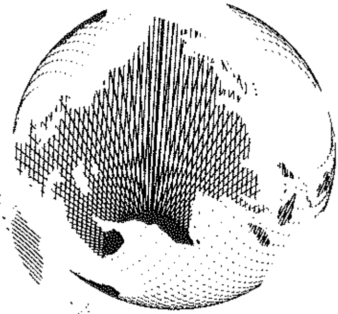

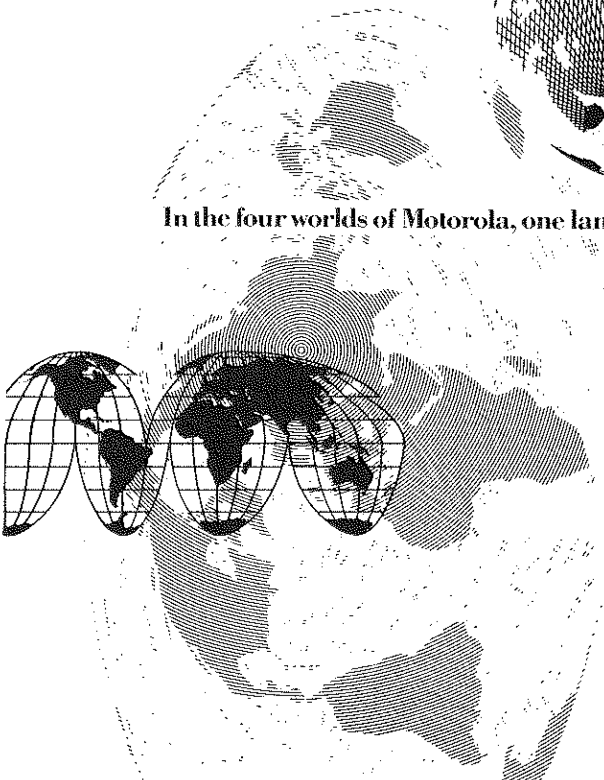

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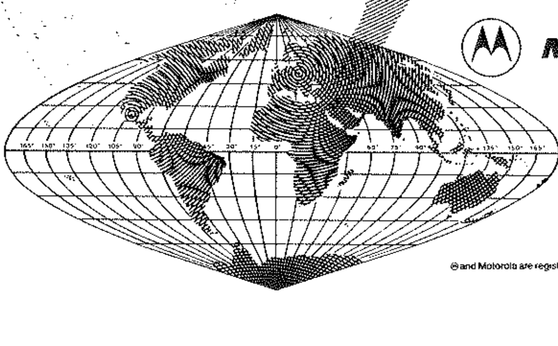
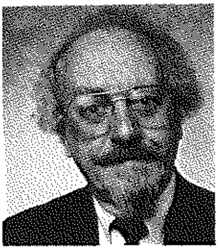


PREFACE



On behalf of the Steering Committee, welcome to the 1992 Joint Symposia (IEEE-APS International Symposium, URSI Radio Science Meeting, Nuclear EMP Meeting). The Joint Symposia are hosted by the University of Illinois at Chicago, in cooperation with the Illinois Institute of Technology, Northwestern University, the University of Illinois at Urbana-Champaign and local industry.

For the first time since the Albuquerque meeting of 1982, the nuclear EMP Meeting is held in conjunction with IEEE-APS and URSI, and several joint technical sessions have been planned. In some instances, an abstract may not appear for a paper listed for presentation either beacuse it was not timely received in the proper format or because only an APS summary was available. The next Nuclear EMP Meeting is planned for 1994 in France.

The preparation of this digest was made possible by the cooperation of my colleagues, Professors S.R. Laxpati and R.A. Schill, Jr., and the assistance of my graduate students J. Ali, S.F. Kawalko and J.T. Kish.

Piergiorgio L.E. Uslenghi
Chair, 1992 Joint Symposia

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Chairs: Ioannis M. Besieris, Virginia Polytechnic Inst. & State Univ.; Richard W. Ziolkowski, University of Arizona

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Xuegang Zeng*, Weigan Lin, Univ. of Elect. Science & Tech. of China

LOCALIZED WAVE REPRESENTATIONS

I. M. Besieris and A. A. Chatzipetros
Bradley Department of Electrical Engineering
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Large classes of nonseparable space-time solutions of the equations governing many wave phenomena (e.g., scalar wave, Maxwell's, Klein-Gordon equations) have been reported recently and will be reviewed briefly here. When compared with traditional monochromatic, continuous wave (CW) solutions, these localized wave (LW) solutions are characterized by extended regions of localization; i.e., their shapes and /or amplitudes are maintained over much larger distances than their CW analogues. Such solutions represent pulses with highly localized transmission characteristics which may have potential applications in the areas of directed energy applications, secure communications and remote sensing. It has been shown that LW solutions can be obtained from a representation that employs a decomposition into bidirectional traveling plane wave solutions; i.e., solutions formed as a product of forward and backward traveling plane waves. The bidirectional representation does not replace the standard Fourier synthesis, but rather complements it, especially for the LW class of solutions.

An extension to the bidirectional traveling plane wave decomposition is presented. New basis functions are used in the superposition resulting in exact, nonseparable, acoustic (scalar-valued) and electromagnetic (vector-valued) wave solutions in a variety of environments (free space, dispersive media, lossy media, metallic waveguides, optical dielectric waveguides). In the bidirectional representation, some of the attractive solutions require smart choices of complicated spectra. In the new superposition, these attractive solutions can be obtained more easily due to the freedom of choice of the basis functions used. This is illustrated by a class of interesting pulses known as sling-shot pulses or X waves. An effort is also made to obtain these solutions by applying the above technique directly to the Fourier representation.

The complicated internal structure of LW solutions can be probed with techniques based on energy conservation principles. Illustrative examples of local energy speeds are given for three LW solutions to the scalar wave equation (Focus Wave Mode, Modified Power Spectrum, Sling-Shot).

APERTURE REALIZATIONS OF EXACT SOLUTIONS TO HOMOGENEOUS WAVE EQUATIONS

Richard W. Ziolkowski

Department of Electrical and Computer Engineering
The University of Arizona
Tucson, AZ 85721

Several new classes of localized solutions to the scalar homogeneous wave and Maxwell's equations have been reported recently. Theoretical and experimental results have now clearly demonstrated that very good approximations to these acoustic and electromagnetic localized wave (LW) solutions can be achieved over extended near-field regions with finite-sized, indepedently-addressible, pulse-driven arrays. Nonetheless, questions concerning the causality of these solutions and, hence, their physical realizability still persist.

It will be shown that it is **only** the forward propagating (causal) components of any solution of the scalar homogeneous wave equation that are actually recovered from either an infinite- or a finite-sized aperture in an open region. The backward propagating (acausal) components result in an evanescent wave superposition that plays no significant role in the radiation process. The exact, complete solution can be achieved only from specifying its values and its derivatives on the boundary of any closed region. By using those LW solutions whose forward propagating components have been optimized over the associated backward propagating terms, one can recover the desirable properties of these LW solutions over the extended near-field regions of a finite-sized, independently-addressible, pulse-driven array. These results will be illustrated with an extreme example - one dealing with the original solution which is superluminal and its finite aperture approximation, a sling-shot pulse. The sling-shot pulsed-beam field is generated by driving an aperture with a superluminal solution and is characterized as a moving interference pattern whose peak intensity moves at a group speed $v_g > c$, even though its constituent signals are traveling at the characteristic wave speed c of the medium. The sling-shot effect is lost once the interference pattern reaches the far field of the aperture.

REAL TIME ARRAY LAUNCHING OF LOCALIZED WAVE PULSED BEAM ENERGY

D. Kent Lewis

Mechanical Engineering Department
Lawrence Livermore National Laboratory
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Livermore, CA 94550

Recent experiments have shown that it is possible to create the Localized Wave (LW) pulse real time in an acoustic environment. The resulting pulsed beam maintains its amplitude and beam width better than either conventional single frequency or wideband beams of comparable frequency content. The spectral bandwidth of the LW pulse is also well maintained. The characteristics of the LW pulses are compared to both Gaussian weighed beams and unweighed, or piston, beams.

The systems used individually addressable arrays and multi-channel source electronics. We launch all necessary source signals simultaneously. The two real time array systems fielded to date are 1) a 25 element Cartesian grid array with 0.5 mm diameter elements on 2.5 mm centers in a 5 by 5 arrangement and 2) a 2 mm diameter central spot with 10 concentric rings of 1 mm widths. The active array elements in both cases are of PVDF.

This presentation describes work done and results achieved at LLNL in the generation of localized wave pulse beams. The effective frequency concept (M. Johnson, Lawrence Livermore National Laboratory, private communication, 1989) will be briefly described as well as the criteria of the effective Rayleigh distance (R. W. Ziolkowski, Localized Wave Engineering and Physics, Phys. Rev. A, vol. 44(6), 3960-3984, 1991) for a pulsed array. Based on these ideas, the LW pulse has achieved better efficiency than the other control beams and has extended its near-field out to 10 times the expected Rayleigh distance.

SPHERICAL SCATTERING OF SUPERPOSITIONS OF LOCALIZED WAVES

Rod Donnelly and Desmond Power*

Memorial University
St. John's Newfoundland
Canada A1B 3X5

The behaviour of an acoustic plane wave or point source field when scattered from a sphere is well understood; in these cases the incident field is monochromatic. The so-called focussed wave mode [FWM] localized wave [LW] solution of the homogeneous wave equation [HWE],

$$e^{i\beta(z+ct)} \frac{e^{-\beta\rho^2/[z_0+i(z-ct)]}}{4\pi i[z_0 + i(z+ct)]},$$

where $\beta > 0$ and $z_0 > 0$ are arbitrary parameters, can represent a concentrated travelling pulse, for large values of β. Taking a particular superposition of FWM pulses, with respect to the parameter β, leads to the so-called modified power spectrum [MPS] LW HWE solution,

$$\frac{1}{z_0 + i(z-ct)} \frac{1}{(s/\beta + a)^\alpha} e^{-bs/\beta},$$

where $s = \rho^2/[z_0 + i(z-ct)] - i(z+ct)$, and where a, α, b, & β are arbitrary positive parameters. Acoustic approximations to the MPS pulse have been launched by investigators and the LW transmission effect has been verified.

Here we present theoretical and experimental results on the acoustic scattering of the MPS pulse from hard spheres. We synthesize the effect of launching and approximation to the MPS pulse from a finite array of transducers by superposing the results obtained from a single transducer when it transmits an appropriate signal from a particular location. In this way we synthesize the array launching of a number of different MPS pulses, and measure the backscattered signal from steel spheres of various sizes. We show how the backscattered data may be used to determine the characteristics of the scatterer. We also indicate how the backscattered data from two spheres may be used to determine the separation of the scatterers. We present a video of a computer graphical simulation of the actual MPS pulse approximation that we launch acoustically; this clearly demonstrates the near field/far field transitional behaviour of the LW pulse.

LOCALIZED WAVE SOLUTIONS IN OPTICAL FIBERS: WAVEGUIDE CONSTRAINTS AND TECHNOLOGY ISSUES

Ashish M. Vengsarkar
AT&T Bell Laboratories
Murray Hill, NJ 07974-0636

In a recent paper (A. M. Vengsarkar et al., J. Opt. Soc. Am. A, 9, June 1992) we demonstrated the existence of localized wave (LW) solutions in optical fiber waveguides. Despite the waveguide constraints introduced by the fiber structure, solutions that resemble nondecaying free-space solutions were obtained using broad bandwidth spectra. In this presentation, we discuss in detail the effect of waveguide constraints on the solution methodology and describe two approaches toward solving the problem. A detailed study of the modified power spectrum is performed, practical issues regarding source spectra are addressed, and distances over which such localized wave solutions maintain their nondecaying nature are quantified. The waveguide structure used for the analysis did not incorporate the effects of losses or the dispersive nature of silica-based glasses. We show by analogy that the presence of material dispersion may not affect the localization of the solutions by considering the case of a plasma-filled metallic waveguide.

One of the notable features of all spectra that give rise to LW solutions is that they are broadband in the optical sense. This leads to the possibility of exciting the higher order LP_{11} mode within the fiber and thus adding to the noise in the system. We will evaluate the behavior of the LP_{11} mode in the fiber for the modified power spectrum (MPS) pulse. We will also direct our attention to the problem of sources - the requirements imposed on them by the spectra, the need for arrays for effective transmission and the robustness of spectra to minor deviations in implementation. Present day state-of-the-art technology is not capable of meeting requirements that will make practical implementation of LW solutions a reality. We address futuristic technology issues and briefly describe efforts that could lead to an efficient LW-solution based fiber optic system.

LOCALIZED ELECTROMAGNETIC FIELDS IN NONDISPERSIVE MEDIA I

Michael C. Moldoveanu and Arthur K. Jordan*
Research Laboratory of Electronics, Massachusetts Institute of Technology
*Permanent Address: Naval Research Laboratories, Washington, D.C., U.S.A.

We present a direct scattering theory for localized electromagnetic fields in three dimensions. Many localized solutions to the three dimensional time dependent wave equation can be derived from group-theoretical considerations. These solutions can be generalized to the vector wave equation to obtain solutions to the classical electromagnetic field equations. The work presented will relate such solutions to Maxwell's equations to the long-standing problem of finding an adequate linear wave formalism to describe relativistic particles. In particular, vector fields satisfying $E=h\omega$ and $\vec{p}$ and $h\vec{k}$ simultaneously are derived, and related to the directive model of atomic radiation (Nadelstrahlung), without recourse to nonlinearities to explain the localization phenomenon.

The inverse problem related to the synthesis of sources for launching localized electromagnetic waves. We present novel analytic solutions to the antenna synthesis problem when the far field in the family of directive waveforms introduced above. Our solutions relate both to paraxial and plane wave approximations to the localized pulses, and to the possibilities of launching these pulses from spatially oscillating sources.

Engineering applications derived from our approach include the synthesis of miniaturized superdirective antennas, and the launching of electromagnetic waves that can approximate with arbitrary precision the localization properties of particles in free space and in linear dispersive media.

RADAR EQUATION AND SIGNAL DESIGN FOR THE ELECTROMAGNETIC MISSILE

Xuegang Zeng *Weigan Lin*

Institite of Applied Physics
University of Electronic Science and Technology of China
Chengdu, 610054, *P. R. China*

ABSTRACT

It has been found that the energy of certain electromagnetic pulses reaching a receiver far away can decrease with distance much more slowly than r^{-2}. Such slowly decreasing electromagnetic pulses are referred to as Electromagnetic Missile (EMM) (Wu, Jour. Appl. Phys., 57(7), 2370(1985)). Many practical EMM sources have been investigated both analytically and experimentally (Shen, Jour. Appl. Phys., 66(9), 4025(1989)). Recently, Myers(Proc. SPIE, Vol. 1226, 290(1990)) and Wen(Jour. Appl. Phys., 70(1), 1(1991)) have reported the backscattered field of the EMM by a plate as well as a sphere, and their analyses show that the backscattered energy decreases still slower than the ordinary case r^{-4}. When these important results are contrasted with the conventional radar, one finds that a large radar return may be obtained if choosing the EMM as a radar signal.

In this paper, the radar equation and the signal design for the EMM are presented based on the characteristics of the EMM. A range-velocity resolution function or Woodward's ambiguity function is obtained analytically, and several plots for range-velocity resolution function are shown. It shows that the radar equation, the signal design and the range-velocity resolution function are different from those for the ordinary radar.

- The concept of radar cross section is changed for the EMM.
- The radar equation is modified for the EMM.
- A suitable radar signal for the EMM is the pulse-position coding differing from the ordinary radar signal.
- The range-resolution is about several centimeters for the EMM.
- The range-velocity resolution function approaches the ideal thumback function.

Monday AM AP-S, URSI-B, NEM Session MA07

Room: Columbus A *Time*: 0820-1140

Inverse Methods

Chairs: L. A. Wegrowicz, MITEK Electronics Ltd.; W. C. Chew, University of Illinois, Urbana-Champaign

0820 **SIMULTANEOUS NONLINEAR INVERSION of PERMEABILITY and PERMITTIVITY in TWO DIMENSIONS USING TIME-DOMAIN DATA**
M. Moghaddam*, Jet Propulsion Laboratory; W. C. Chew, University of Illinois, Urbana-Champaign

0840 **INVERSION of REAL TRANSIENT RADAR DATA USING the DISTORTED-BORN ITERATIVE ALGORITHM**
William H. Weedon*, J. E. Mast, W. C. Chew, University of Illinois, Urbana-Champaign; H. Lee, Univ. California at Santa Barbara; J. P. Murtha, Univ. of Illinois at Urbana-Champaign

0900 **RECONSTRUCTION of CONTINUOUS and DISCONTINUOUS REFRACTIVE INDEX PROFILES from POWER MEASUREMENTS of REFLECTED FIELDS**
G. Mazzarella*, G. Panariello, Universita di Napoli

0920 **COMPARISON of OPTIMIZATION PROCEDURES for RADAR SCATTERING MATRICES**
Xin Zhang*, Chuan-Li Liu, Yoshio Yamaguchi, Wolfgang-M Boerner, University of Illinois at Chicago

0940 **SYNTHESIS of UNEQUALLY SPACED ARRAYS AS INVERSE PROBLEM**
L. A. Wegrowicz*, MITEK Electronics Ltd.; N. Rao Atluri, McGill University; F. Bardati, University of Rome "Tor Vergata"

1000 **Break**

1020 **POLYNOMIAL CHARACTERIZATION of INHOMOGENEOUS MEDIA and THEIR INVERSION USING NON-PLANE WAVE SOURCES**
Masoud Mostafavi*, San Jose State University; Wen-Chin Lan, Taiwan Microwave Company

1040 **DIRECTION FINDING of MAGNETOSPHERIC VLF/ELF WAVES BASED on the SIMULTANEOUS MEASUREMENT of MULTIPLE FIELD COMPONENTS**
Masashi Hayakawa*, The University of Electro-Communications; Shin Shimakura, Chiba University; Masaki Shimizu, K. Hattori, Nagoya University; Naofumi Iwama, Toyama Prefectural University

1100 **APPLICATIONS of the NEW GENERALIZED FORM of MAXIMUM ENTROPY METHOD to SOLVING INVERSE PROBLEMS**
Anisa T. Bajkova*, USSR Academy of Sciences

1120 **TARGET FEATURE EXTRACTION of FREQUENCY DOMAIN DATA with OPTIMAL RATIONAL APPROXIMATION**
Supeng Liao*, D. G. Fang, X. G. Li, East China Institute of Technology

COMPARISON OF OPTIMIZATION PROCEDURES FOR RADAR SCATTERING MATRICES

Xin Zhang, Chuan-Li Liu, Yoshio Yamaguchi and Wolfgang-Martin Boerner

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Basic principles of radar polarimetry are introduced and various optimization procedures for the propagation (scattering) range operator equation and the received power expressions are presented and compared. It is assumed that the radar is a complete coherent dual orthogonal (A,B) transmit/receive antenna system of high channel isolation and antenna side-lobe reduction, where in the case of wave interaction with a discrete stationary point target the propagation (scattering) matrix is given by the 2x2 coherent Jones (Sinclair) matrix [S(A,B)] and/or the 3x3 or 4x4 complex covariance matrix [Σ(A,B)], and the 4x4 Mueller (Kennaugh) power density matrix [M] for the symmetric (monostatic reciprocal: $S_{AB} = S_{BA}$) or the asymmetric (general bistatic, monostatic non-reciprocal: $S_{AB} \neq S_{BA}$) partially coherent cases, respectively. Separate optimization procedures are here introduced for the symmetric case, demonstrating that for the coherent (deterministic) scattering scenario the solutions are identical, and so approximately also for the partially polarized case, whereas for the partially coherent case a more elaborate optimization procedure for the 3x3 covariance and/or 4x4 Mueller matrices is employed. It is shown that there exist in total five unique pairs of characteristic polarization states for the symmetric scattering matrix of which two pairs, corresponding to the cross- polarization (x-pol) null and co-polarization (co-pol) maxima, are identical; whereas the x-pol max and x-pol saddle point pairs are distinct. These three pairs of orthogonal characteristic polarization states are also mutually at right angles to one another on the polarization sphere. The fifth pair, the (in general) non-orthogonal co-pol null pair, lies in the plane spanned by the co-pol max, or equivalently the x-pol null, and the x-pol max pairs which determine the 'target characteristic plane (circle) of Kennaugh'; and together with the orthogonal x-pol saddle point pair, being at right angles to this plane, they re-establish Huynen's 'polarization fork' concept. The various approaches are compared by two illustrative examples in which, besides the 'polarization forks', also the co-pol and x-pol power density plots and the relative co/cross-polarization phase (polarimetric correlation coefficient) plots are presented.

Monday AM URSI-E, NEM Session MA12

Room: Columbus I/J *Time*: 0820-1200

Coupling to Cables

Chairs: R. L. Gardner, Phillips Laboratory, USAF; Jack Bridges, IIT Research Institute

0820 **CALCULATION of TYPICAL RESPONSES of AERIAL LINES to a HEMP**
F. Arreghini, M. Ianoz*, Ecole Polytechnique Federale de Lausanne; W. Radasky, K. Smith, Metatech Corporation

0840 **TRANSIENT COUPLING to BURIED BARE and INSULATED CABLES**
G. E. Bridges*, The University of Manitoba

0900 **SIMPLIFIED APPROACH for the DETERMINATION of DISTURBING VOLTAGES INDUCED on CABLE BUNDLES**
B. Demoulin*, C. Poudroux, M. Rifi, P. Degauque, Universite de Lille

0920 **SUSCEPTIBILITY of HIGH VOLTAGE MULTICONDUCTOR OVERHEAD LINES (EDF) to FAST TRANSIENT ELECTROMAGNETIC PERTURBATION**
Ch. Dumond*, O. Dafif, M. Besse, Bernard Jecko, IRCOM URA CNRS No 365, Equipe "EM"; N. Recrosio, F. Morillon, E.D.F. Lab d'Essais a Haute Tension; R. Ott, Electricite de France

0940 **TRANSFER IMPEDANCE SETUP for MULTICONDUCTOR SHIELDED CABLES**
R. Boucheteau, M. Cazajous*, Commissariat a l'Energie Atomique; B. Demoulin, Univ. des Sciences et Tech. de Lille

1000 **Break**

1020 **COMMON and DIFFERENTIAL MODE INJECTION in SHIELDED MULTICONDUCTOR TRANSMISSION LINES**
J. L. ter Haseborg*, Technical University Hamburg-Harburg; F. Wolf, C. Plath GmbH

1040 **A NEW ALGORITHM for ANALYSIS of COMPLEX GROUNDING STRUCTURES**
Han Fang*, Northern Jiaotong University

1100 **NONLINEAR RESPONSES for IMPULSE CURRENTS on FERROMAGNETIC SHIELDS**
W. J. Croisant*, C. A. Feickert, M. K. McInerney, US Army CERL

1120 **TRANSFER IMPEDANCE of USER-INSTALLED CONDUIT TERMINATIONS**
Llewellyn Jones*, Ahmed Abdelgany, William Slauson, Raytheon Company

1140 **ELECTROMAGNETIC COUPLING CALCULATIONS USING SPREADSHEET PROGRAMS on PERSONAL COMPUTERS**
Lothar O. Hoeft*, BDM International, Inc.

CALCULATION OF TYPICAL RESPONSES OF AERIAL LINES TO A HEMP

by

F. Arreghini, M. Ianoz
Ecole Polytechnique Fédérale de Lausanne
Lausanne, Switzerland

W. Radasky, K. Smith
Metatech Corporation
Goleta, CA, USA

Calculations of the response of above-ground conductors such as power or communication lines to HEMP are needed to translate any incident HEMP environment waveform to currents and voltages at a facility entry point. These values can then be used for designing an appropriate protection philosophy. The calculation approach is important because: (1) long lines are able to collect a substantial amount of the HEMP energy and direct it toward a single entry point of the system, and (2) it is not feasible to develop a HEMP field simulator capable of illuminating a sufficient length of a line in a threat-relatable fashion (high-level plane wave field over several hundred meters of line). For these reasons accuracy of the HEMP coupling calculations is very important.

This paper will discuss recent efforts in Lausanne , Switzerland and Metatech Corporation in Goleta, California to perform a set of calculations of typical responses of aerial lines to a HEMP with the aim to provide peak current and voltage values of conducted disturbances for the new IEC HEMP standard that is now currently under development in TC 77, Working Group 10. These calculations were performed using the "Longmire" incident electromagnetic field pulse which is considered more realistic than the classical "Bell-Laboratory" waveform.

Comparisons between time and frequency domain calculations will be provided, showing results in good agreement. In addition, a recent experiment performed at the Centre d'Etudes de Gramat (France) has provided the opportunity to perform a code/data comparison which shows also a good agreement between measured and computed values (fig. 1). The paper will discuss the advantages of the various methods used and the reasons for the differences observed.

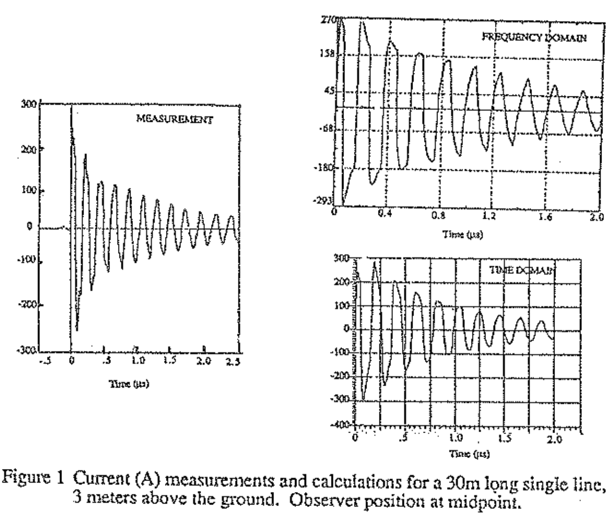

Figure 1 Current (A) measurements and calculations for a 30m long single line, 3 meters above the ground. Observer position at midpoint.

TRANSIENT COUPLING TO BURIED BARE AND INSULATED CABLES

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The coupling of transient sources to buried cables and pipes is important for the study of EMP and lightning effects as well as having many remote sensing applications. In this work, the current induced on infinitely long bare and insulated cables buried in a lossy half-space is formulated. For this problem a quasi-TEM transmission line approach is commonly employed as a solution technique. Here the cable is modeled by its equivalent circuit parameters and the incident field is modeled as a distributed source along its axis. This approach is relatively simple and only requires the accurate determination of the cable parameters. Unlike overhead cables, the propagation characteristics of a buried cable is strongly dependent on the electrical parameters of the earth, the burial depth when compared to the skin depth, and the insulating properties of the cable. Insulated and bare (grounded) cables have a dramatically different behavior. Further, the transmission line approach assumes the discrete modes dominate the induced current, ignoring the surface wave and radiation spectral contributions. Several of these issues have been examined in the frequency domain (D.A. Hill, IEEE Trans. Geoscience Remote Sensing, 720-725, 1988).

In order to study the accuracy of the transmission line approach, an exact solution is developed for determining the current induced on a buried cable system. A spectral domain formulation is used (K. Tsubota and J.R. Wait, Geophysics, 941-951, 1980) where a solution is given in the standard integral form, with time domain results obtained using the Fourier transform. Examples are presented for typical cable geometries and earth parameters. The simple result formulated by Vance (E.F. Vance, *Coupling to Shielded Cables*: Wiley, 1978) giving the induced current on a buried cable due to an exponential transient incident plane wave is compared to the more accurate theory.

SIMPLIFIED APPROACH FOR THE DETERMINATION OF DISTURBING VOLTAGES INDUCED ON CABLE BUNDLES

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If a transient electromagnetic wave impinges on cable assemblies, one of the problems is to determine the voltages at the ends of the cable bundle. However, in most practical cases, only on or two cables or wires inside the bundle are connected to very sensitive equipments which must be protected.

The calculation of the disturbing voltages can be made by using the coupled transmission line theory. In a first step, the analytical solution in the frequency domain depends on the matrix inductance and on the matrix capacitance. Each element of these matrices characterizes the lineic parameters of the coupled lines. In the general case, it is necessary to make numerous measuremrents to get each inductance and capacitance coefficient. From these datas, it is possible to deduce the propagation constants corresponding to the various eigenmodes propagating along the cable assembly and which are needed to compute the voltage amplitude induced on the various wires.

We propose, in the scope of this paper, to simplify this method by using another approach for which the inductance coefficients are calculed approximately from the well-known formulas given by the theory of coupled lines situated in a homogeneous dielectric medium. Then we assume that the equivalent permittivity of the dielectric medium can be deduced from the velocity of the common mode propagating on the cable and which can be measured very easily. From the knowledge of the inductance coefficients and of the equivalent dielectric permittivity, the capacitance coefficients are determined.

A comparison between the voltages predicted by the rigorous method and those got with this simple approach will be described. The shift in the resonance frequencies will be considered and the error margin on the disturbing voltage amplitudes is given both at low and high frequencies.

Lastly an application of these results into the time domain is given. The peak amplitude and the energy on the loads are calcuted through the rigourous modal theory and with the simplified approach.

SUSCEPTIBILITY OF HIGH VOLTAGE MULTICONDUCTOR OVERHEAD LINES (EDF) TO FAST TRANSIENT ELECTROMAGNETIC PERTURBATION

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This article presents the theoretical and experimental study of high voltage large multiconductor overhead lines susceptibility to a nuclear electromagnetic pulse (NEMP).

This study aims to determine induced currents (rise time, amplitude) on lines, taking into account their geometrical configurations (height, sagged wires...), their endings (loads in high voltage substations) and the electrical properties of soil. So, currents and overvoltages propagating in the sensitive devices of line endings could be calculated.

These currents are obtained by a space-time integral equation which is solved by the "moments method" joined to a second order polynomial representation (the chosen interpolation is Lagrange's one).

Two applications will be presented:

- Experimental simulation by a strip-line simulator (EDF) excited by an electromagnetic pulse generator. The small-scale line is located in the test zone above a perfectly conductive ground. A comparison between theory and experimentation is systematically done. A rigorous method is used for the theoretical study.

- Theoretical study of coupling between a nuclear electromagnetic pulse and high voltage loaded lines. This study will be performed in real size with the electrical properties of soil defined by (ε_r, σ). The currents on the line above the surface are driven by the total electric field (incident plus reflected) calculated without approximation. However, Fresnel approximations are used to compute fields reradiated by the line.

Coupling NEMP - high voltage lines (EDF) will be presented for differents parameters:

- line's height
- conductors number and radius
- electrical properties of soil
- angle of incidence

This study will be performed in order to determine the most penalizing cases.

TRANSFER IMPEDANCE SETUP FOR MULTICONDUCTOR SHIELDED CABLES

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Transfer impedance (T.I.) is an useful parameter for determining the electromagnetic field penetration into a shielded cable. For several years, methods and test setups have been developed for coaxial or shielded twisted pairs. Accurate and reliable measurements for these kinds of cables can be performed in many laboratories.

This paper presents an original setup built in our NEMP laboratory for the measurement of the T. I. of multiconductor cables. Its main characteristics are the following : number of conductors inside the cable (up to nineteen), length of the tested cable (2 m) and frequency bandwidth (from 10 kHz up to 15 MHz). T. I. can be measured for two configurations : single common mode (one conductor/shield) and total common mode (all the conductors linked together)

The quadriaxial structure of the setup avoids the use of a Faraday cage. Wires commutation is made by means of miniature relays located inside two screened boxes at both ends of the line. Instrumentation consists in a frequency generator coupled with a broad band power amplifier and a selective voltmeter fed with a battery. The commutation principle could be extended for the measurement of the T.I. in differential mode.

Setup calibrations were achieved with initial measurements of wellknown shielded cables such as coaxial with a solid outer conductor and shielded twisted pair. Good results were obtained for frequencies up to 10 MHz, beyond this bandwith, perturbations arose at the ends of the cable. The resolution of the measurements is about $10^{-5}\Omega/m$.

The first tests performed on a nineteen conductors cable show that there are differences between single common mode and total common mode measurements. Furthermore, the position of the conductor inside the cable is a significant parameter in the case of an helicoïdal shield, but not in the case of a solid outer conductor or a braided shield.

In addition to this, the setup enables the measurements of the lineic impedance Z_{ii} of each conductor and of the coupled lineic impedance Z_{ij} of two conductors i and j. These parameters can be used to determine the signal induced inside a cable by mutual coupling.

COMMON AND DIFFERENTIAL MODE INJECTION IN SHIELDED MULTICONDUCTOR TRANSMISSION LINES

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Abstract

In order to protect electronic systems against transients, nonlinear protection circuits are necessary. In case of multiconductor transmission lines connected with sensitive electronic systems, a lot of protection circuits have to be installed. By application of nonlinear filter pin connectors it is possible to arrange the filters for the complete number of line conductors within a plug.

Beside the suppression of interfering transients in multiconductor transmission lines by nonlinear filter pin connectors the influence of these protective devices on the transmission of the signals is of interest. In case of RF- and data lines the transmission and reflection behaviour as well as the RF-coupling between individual filter pins are of special significance.

While in previous papers (e.g. NEM'90) the transient response and transmission characteristics of nonlinear filter pins have been discussed exclusively, in this publication results will be represented showing the behaviour of nonlinear filter pin connectors installed in special plugs in connection with shielded multiconductor transmission lines. Concerning the transient response, the test pulses have been injected on the line shield by means of a current probe. Dependent on the individual line conductors, (outer and inner conductors), connected with different filter pins on the inside of the plug it exists a common mode as well as a differential mode excitation.

Measurement results in the time domain will be represented showing the transient response for linear and nonlinear filter pin connectors dependent on different line terminations. Measurement results in the frequency domain will show the influence of the line and the plug, containing the filter pins, on the RF-characteristics.

A NEW ALGORITHM FOR ANALYSIS OF COMPLEX GROUNDING STRUCTUES

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It is often involved to design and analyse various kinds of grounding structure in order to ensure normal operation, or safe protection, of power system and communication system against electromagnetic pulse (T. Nagono, Electr. and Comm. Jpn. pt.1, 68, 109–116, 1985). The resistance of the grounding structure is one of the most important parameters in analysing its EMP response. With the rapid development of computer technology, many numerical algorithms are becoming available (R. P. Nagar, IEEE Trans. PAS–104, 1985).

In this paper, the finite element approach is used and a new algorithm is presented to calculate ground resistance and leakage currents. This algorithm could be applied to treat various kinds of complex grounding structure composed of conductive grids and rods. Furthermore, the distribution of the earth potential, touch voltage, and step voltage caused by EMP currents in the ground could be also calculated by the algorithm.

In the algorithm, the image effect of the grounding structure is taken into account in addition to that of the ground itself. For a complex grounding structure, the average current distribution could not be assumed as in the case of a single conductive rod, because the leakage currents in all element are not the same. In the paper, it is assumed that if the wavelength is much greater than maximum size of a complex grounding structure, the ground would be equipotenial, i.e., the potentials on all the elements segmented from the ground are the same with that of the whole grounding system. Furthermore, it is assumed that the potential in each element is equal to the potential at its central point, and that the leakage current is uniformly distributed. It is shown that the element resistance matrix [R], element current matrix [I], ground voltage V_g, EMP current I in the ground, and ground resistance R_g satisfy the following relations

$$[\mathbf{R}][\mathbf{I}] = V_g[1] \tag{1}$$

$$V_g = R_g I \tag{2}$$

$$R_g = \frac{1}{[1]^T [\mathbf{R}]^{-1} [1]} \tag{3}$$

For higher accuracy, each element could be further subsegmented into a number of subelements. Two examples are given, and compared with the experiment results which are in good agreement with the computation.

NONLINEAR RESPONSES FOR IMPULSE CURRENTS ON FERROMAGNETIC SHIELDS

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An approximation to a thin-walled cylindrical geometry problem considers a planar ferromagnetic sheet of thickness d with electrical conductivity σ, differential magnetic permeability $\mu_d(H)=dB(H)/dH$ (assumed to be a scalar function of the magnetic field intensity H), and saturation magnetization B_s subjected to an impulse sheet current with total charge per unit length Q_o applied transversely along the outer surface and a vanishing magnetic field intensity condition at the inner surface. Mathematical analysis in conjunction with numerical analysis is used to characterize the peak value of the transient electric field response induced at the inner surface E_{peak} and the time of the peak t_{peak}.

A dimensionless formulation of the nonlinear problem for an arbitrary relative differential permeability $\mu_{rd}(H)=\mu_d(H)/\mu_o$ reveals a fundamental combination of the nonmagnetic parameters:

$$\beta = \frac{Q_o}{\sigma d^2}, \tag{1}$$

which defines an applied pulse parameter for the problem. If E_{peak} and t_{peak} are referenced to the constant permeability that would give the same result from the solution to the linear problem, then one can express E_{peak} in terms of an effective permeability $\mu_E(\beta)$

$$E_{peak} = 5.9220537270\frac{Q_o}{\mu_o\mu_E(\beta)\sigma^2 d^3} \tag{2}$$

and t_{peak} in terms of an effective permeability $\mu_T(\beta)$

$$t_{peak} = 0.091751715\mu_o\mu_T(\beta)\sigma d^2, \tag{3}$$

where the functions $\mu_E(\beta)$ and $\mu_T(\beta)$ corresponding to a given $\mu_{rd}(H)$ are calculated numerically. Numerically, $\mu_E(\beta)$ and $\mu_T(\beta)$ exhibit the following behavior: for very small pulses both approach the initial value of the relative permeability so that to a good approximation $\mu_E(0)=\mu_T(0)=\mu_{rd}(0)$; near $\beta=B_s/2$ both exhibit the onset of saturation, which is in close agreement with that predicted by the limiting nonlinear theory for a step magnetization curve; and for extremely large pulses both approach the permeability of free space so that to a good approximation $\mu_E(\infty)=\mu_T(\infty)=\mu_{rd}(\infty)=1$.

An applied pulse parameter that includes B_s can be inferred from a dimensionless formulation for $\mu_{rd}(H)=B_s exp(-H/H_c)/\mu_o H_c$

$$\zeta = \frac{Q_o}{\sigma d^2 B_s}. \tag{4}$$

Moreover, the same combination of parameters is found in the analytical solution obtained using the limiting nonlinear theory for a step magnetization curve. Preliminary numerical results indicate that ζ is also applicable to other permeability representations.

TRANSFER IMPEDANCE OF USER-INSTALLED CONDUIT TERMINATIONS

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Flexible conduits are used on many systems to provide better shielding than that obtainable with a standard double overbraid. However, in many designs the flexible conduit is terminated in the field with user-installable terminations. A test program was conducted to evaluate the transfer impedance of conduits with user-installed terminations. Four vendors provided user-installable fittings for their own conduit. All conduits were 1 meter long and had a 0.75 inch inner diameter. Each of the vendors use different termination methods but they all rely on threaded connections to terminate the conduit to the connector.

The transfer impedance measurements were made with a standard quadraxial fixture. Calibration of the fixture was performed using a known solid and perforated tube. Data was obtained from 5 Hz to 200 MHz using the HP 3577 network analyzer.

The transfer impedance was measured and recorded for three different torque values (85 inch-pounds, 45 inch-pounds, and 20 inch-pounds). The transfer impedance is strongly dependent on the torque value. Typically the difference between hand-tightening and torquing to 45 inch-pounds is approximately 10 dB at 10 MHz with little improvement at higher torque values. The transfer impedance is relatively flat out to 100 KHz and then exhibits a slight diffusion dip before increasing above 1 MHz. This increase is characteristic of leakage through apertures. Differences in the transfer impedance for the four vendors are shown. The transfer impedance with the user-installed terminations is compared to data for factory terminations. In general, the data shows that the transfer impedance for the conduit is dominated by the termination method.

ELECTROMAGNETIC COUPLING CALCULATIONS USING SPREADSHEET PROGRAMS ON PERSONAL COMPUTERS

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(505) 848-5399 Fax: (505) 848-4029

The advent of personal computers with sophisticated spread sheet programs has given the engineer or scientist a powerful tool for quickly and accurately calculating the electromagnetic coupling in systems. The spreadsheet computational technique emphasizes how electromagnetic energy flows from the source or culprit to the receiver or victim. Each step in the computational process is represented by a relatively simple, easily understood coupling model. This allows the analyst to see the results of all the intermediate steps in the calculation, and gain a much clearer insight into the coupling process than can usually be obtained from more elaborate special purpose computer codes.

The computational technique is based on the concept that an electromagnetic coupling calculation can represented as a product of transfer functions. In the frequency domain these are phasors, have a magnitude and phase. Each of these can usually be broken down into quite simple formulations. Each is calculated by one column of the spread sheet. Frequency, with either a linear or logarithmic distribution, is represented by the rows of the spreadsheet. The plotting capabilities of the spread sheet can be used to present the data in graphical form. As in most EMC calculations, the magnitude only can be calculated if desired. If phase is also calculated, the results can be used to transform time domain waveforms.

This paper will explain the technique and present an example of coupling through cable shields. The common mode currents and voltages on the overbraid, the twisted pair shield and the twisted pair wires were calculated.

The use of a spread sheet frees the electromagnetic analyst from the computational housekeeping and allows attention to be focused on the physics of the situation.

Monday PM URSI-A E, NEM Session MP12

Room: Columbus I/J *Time*: 1320-1700

EMP-System Test Results

Organizer: Hagen Schilling, WWD ABC-Schutz

Chairs: Hagen Schilling, WWD ABC-Schutz; C. D. Taylor, Mississippi State University

1320 **CONCLUSION of SYSTEM TESTS in the EMP-SIMULATOR of WWD ABC-SCHUTZ**
Hagen Schilling*, WWD ABC-Schutz

1340 **APPLICATION of the GERMAN STANDARDS for NEMP-SYSTEM TESTS**
J. Nedtwig*, Telefunken System Technik GmbH

1400 **THE SHIELDING EFFECTIVENESS of SEAMS and VENTS in TACTICAL SHELTERS**
R. A. Perala*, J. R. Elliot, R. S. Collier, Electromagnetic Applications, Inc.

1420 **SHIELDING EFFECTIVENESS of METAL ENCLOSURES EXPOSED to DIPOLE FIELDS**
Nobert Esser*, ABB Management Services GmbH; Hagen Schilling, WWD ABC-Schutz

1440 **A SIMPLE MEASUREMENT METHOD for ESTIMATING the SHIELDING EFFECTIVENESS of UNDERGROUND BUILDINGS**
B. Z. Raisch*, Markus Nyffeler, Bruno Brandli, E. Dorr, B. Reusser, NC Laboratory

1500 **Break**

1520 **LOW LEVEL SIMULATION of the EMP ENVIRONMENT in a TELECOMMUNICATIONS TOWER**
Torbjorn Karlsson*, Sven Garmland, EMTECH

1540 **EMP COUPLING to SHIPS: ANALYSIS of DIFFERENT TECHNIQUES**
Herve Grauby*, GERAC; Jean-Pierre Percaille, Centre d'Etudes de Gramat

1600 **A SCALE-MODEL SIMULATOR for SYSTEM TESTS**
Christian Braun*, W. Graf, H. U. Schmidt, Fraunhofer Institut fur Naturwissenschaftlich-Technische Trendanalysen (INT)

1620 **SURFACE CURRENT DENSITY INDUCED on AIRCRAFT ILLUMINATED by EMP**
Chung-Hsuing Yeh*, Dau-Chyrh Chang, Chung Shan Inst. of Science and Tech.

1640 **MODAL EXCITATION of a LARGE AIRCRAFT USING MULTIPLE ANTENNAE**
Lothar O. Hoeft*, Joseph S. Hofstra, BDM International, Inc.; William D. Prather, Phillips Laboratory

CONCLUSION OF SYSTEM TESTS IN THE EMP-SIMULATOR OF WWD ABC-SCHUTZ

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Since 1981 Germany has tested many systems and electric equipment in the EMP simulator of the WWD-ABC-Schutz which is located in Munster. This simulator is a bounded wave system for vertical polarized fields. The transmission line has a length of more than 100 m. In the working volume with the dimensions L = 20m, W= 12 m and H = 8 m EMP pulses with a field strength up to 75 kV/m and a rise time of less than 10 ns (10 - 90%) with a decay time of 10 μsec can be simulated. Pictures and technical details of this simulator with the two pulser systems and the data channels will be shown in the paper.

When we started in 1981 with our first system tests we applied the same test procedure which is used in many other EMP-test laboratories. Beginning with low field strength we measured the induced currents on most of the cabels. Then we extrapollated these measured values to the real threat and continued with upset and go-no-go tests. This test philosophy was changed because of the fact that we could reduce the total test time for systems by starting with a go-no-go test first and increasing the field strength up to the values where the permanent damages were found. In the next step we measure the induced currents and concentrate our measuring points to these cable connections where we have seen upsets or permanent damages. After analysing these results we develop and install hardening devices. At the end of the test we make a final acceptance test with 75 kV/m.

We have tested more than 90 different systems and smaller electric equipment. A conclusion of these test results of CC-systems, vehicles, tanks, aircraft-systems, NBC-protection equipment ect. will be shown in the paper. Some examples of these test results will be discussed in detail. We found that many systems even if they were not specially EMP hardened were not affected by EMP fields. In case of upsets or permanent damages the protection devices or hardening methods were not very cost effective. Finally some critical and unsolved problems like overtesting, safety margins, circuit analysis, cable coupling and international standardization of the test procedures will be discussed in the paper.

APPLICATION OF THE GERMAN STANDARDS FOR NEMP-SYSTEM TESTS

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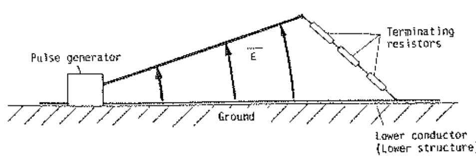
Abstract:
Since the early eighties german committees of standardization (NEA 760) for the german office of armement and procurement (BWB) define new standards for NEMP and LIGHTNING protection. These standards contain not only management rules, effective test procedures and protection measures but give also effective hints how to realize NEMP tests of "whole" systems. Since these new standards are nearly completed and in english available, Lit. /1/, it is the intention of the author (member and chairman of several committees) to give an overview of these standards and to present there advantages.

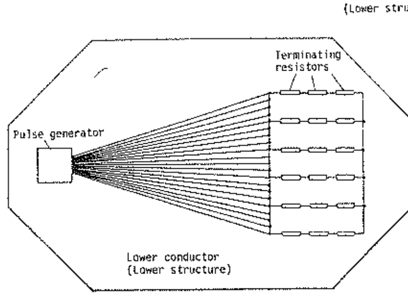
Before starting complete NEMP system tests several actions are to be carried out. First: Analyzing of all system functions, second: Definition of a test plan with definition of the test points, third: Selection of a suitable NEMP simulator, fourth: Low level tests in the simulator, fifth: Computer aided analises with calculations fo the expected distortions under threat levels, sixth: Threat level test and valuation of the damages, seventh: protection measures.

For all these activities the German NEMP Standards VG 96 900-907 offer helpful regulations. For an example the standard VG 96 903, part 50, NEMP tests in bounded wave guides, demand the definition of the field homogenity by a field mapping in the simulator.

The author gives not only an overview of the standards but presents the essentials of elected standards for NEMP testing and protections.

Lit. /1/: Book EMV3 (in English),
VDE-Verlag, Germany Berlin and Köln (DM 150)





THE SHIELDING EFFECTIVENESS OF SEAMS AND VENTS IN TACTICAL SHELTERS

by

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R.S. Collier

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ABSTRACT

In this paper the SE of tactical shelters is described. The paper emphasizes a shelter without appendages. Also, the emphasis is on the shielding provided by the door seams, edge seams, and with some considerations of ECU vent openings.

Measurement techniques are described for determining the transfer impedances in-situ. It is shown that the SE of shelters can be completely specified in terms of the transfer impedances. It is shown how these transfer impedances are included in three dimensional numerical analysis techniques.

Experimental results are compared to numerical results for the SE of shelters for two important cases. These cases are for MIL-STD-285, and for EMP simulation in an EMP simulator. It is shown that the results generally agree within a factor of two. In addition, the relationship between MIL-STD-285 SE and EMP SE is described. The EMP field structure within a shelter is also described and interpreted. Both evanescent and propagating modes are discussed.

In the first example, a simulated Nuclear Electromagnetic Pulse (NEMP) plane wave from a U.S. Army NEMP Simulator was incident on a metallic tactical shelter having dimensions approximately 10' x 8' x 7'.

The main penetration into the interior is via seams around the edges of the door. Using a special measurement method which we developed (SIMM - Seam Impedance Measurement Method) under contract to Harry Diamond Laboratories (HDL) the impedances of the seams were measured. The impedances were input into our 3D Finite Difference solution of Maxwell's equations for the shelter interaction with the EMP, and internal EM fields and the response of an internal conductor were calculated and compared with measurements.

A second example, comparisons are made between numerically calculated results and MIL-STD-285 Se measurements. Excellent agreement is obtained.

inductive / resistive Seam

SHIELDING EFFECTIVENESS OF METAL ENCLOSURES EXPOSED TO DIPOLE FIELDS

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The shielding effectiveness of metal enclosures is a well known solution of Maxwell's equations, if the incident electromagnetic field is assumed to be a plane wave. With respect to NEM problems this waveform is questionable for some applications. When considering the source region EMP for example, the assumption of a plane wave may be incorrect up to the Megahertz range, and when measuring the shielding effectiveness of a cabin, spherial waves may be incident on the shield over a wide frequency range due to the close distance of the antenna (MIL STD 285).

It could be misleading to compare these measurements with calculations based on an incident plane wave, and even more important, to use these measurements uncorrected for an incident plane wave such as the high altude EMP.

It is therefore important to understand analytically, if and to what extend the shielding effectiveness depends on the distance between source and shield.

This paper presents the analytical solution of Maxwell's equations for this problem and shows the influence of a variation of this distance on the calculated shielding effectiveness. An electric or magnetic dipole or a linear combination of both can be used as source, and all components of the electromagnetic field can be calculated at each detector point inside of the shield.

To allow an analytical solution the shield was assumed to be spherical. Radius, thickness and electrical parameters of the material as well as source distance and dipole parameters are the input data of the program.

Measurements of the shielding effectiveness of cabins at different detector points are compared with analytical predictions to contribute to experimental validation and discussion of accuracy and limits of the model.

A SIMPLE MEASUREMENT METHOD FOR ESTIMATING THE SHIELDING EFFECTIVENESS OF UNDERGROUND BUILDINGS

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In this paper, experimental techniques for determining the shielding effectiveness of a buried facility are discussed. The measurement method emphasizes simplicity, rather than a high dynamic range or accuracy. Requirements for shielding of buildings larger than 60 dB are, in most cases, unnecessary. A dynamic measurement range of 60 to 80 dB is reasonable from an engineering standpoint, and is sufficiently high for practical applications.

Shielding effectiveness of a buried building is measured by comparing signals received by two antennas: one located outside the underground building on the earth's surface, and the other located within the building. Signals can be received from either a controlled radiating source, or from existing broadcast stations.

When working with signals from a controlled source, the transmitting antenna should be located far from the receiving antennas, so that the incident field on the building appears as a plane wave. With this approach, the shielding behavior of the building can be evaluated at many different frequencies.

A simpler test approach is to use existing broadcast stations as a source. The first step in this procedure is to examine the radiating power and frequencies of local emitters near the facility. With these data, along with a knowledge of the transmitter distance, the signal strength received at the external antenna may be estimated. Similarly, with an estimate of the designed shielding effectiveness of the building, the internal antenna response may be roughly estimated. This provides initial information as to the feasibility of measuring an internal response from the broadcast source.

Regardless of the type of excitation source used, the shielding effectiveness of the building may be evaluated experimentally by means of a spectrum analyzer or by a HP3577A network analyzer. Large differences in the shielding effectiveness can be found for different polarizations and antenna locations. In practical cases, the shielding surface of the facility can be divided into smaller zones, and local shielding measurements made. Furthermore, for critical facilities, periodic testing of this kind may be conducted to evaluate the shielding degradation with time.

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*On Sabbatical leave from: RAFAEL, P.O.Box 2250, HAIFA, Israel

LOW LEVEL SIMULATION OF THE EMP ENVIRONMENT IN A TELECOMMUNICATIONS TOWER.

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The effects of an electromagnetic environment that will be created by a high altitude EMP event have been investigated for observation locations inside the 150 m high Kaknäs tower in Stockholm, Sweden. The tower was illuminated with a low level CW field, and measurements were taken at a number of test points inside the tower. In order to obtain the properly extrapolated responses corresponding to a real incident EMP field, the simulation was carried out with several different considerations in mind. One concern of particular importance was how to perform simulation on a structure having the large dimensions of the Kaknäs tower.

The transfer function from a reference point to the test point was determined. Both amplitude and phase were measured. No nonlinear effects were taken into account. The reference outside the tower was chosen at a point where the incident field could be calculated.

First, the required plane wave quality of the simulated wave was studied. External currents induced on the tower were studied in a computer model by Dr F. M. Tesche, and different illuminations from a number of distances up to 500 meters were made. It was concluded that an illumination of the tower could be done from a location as close as around 140 m and still be correctly extrapolated. This was due to the fact that coupling into the tower was concentrated to a small number of entry points. The local coupling at each point of entry dominated over the propagated signal from other entry points.

A short dipole antenna was first used as an illuminator in order to cover the entire frequency range of 100kHz – 100 MHz. It turned out that this was insufficient below 1 MHz. An elegant solution to the problem was the infrequently used illuminator called the $\mathbf{p} \times \mathbf{m}$ -antenna, described by Carl E. Baum in the early 70's. This antenna is characterized by a near field that in one direction has exactly the ratio 377 Ω between the electric and magnetic field vector. Before the illumination was made a small study of the antenna was undertaken, and different scale models were tested.

The erected $\mathbf{p} \times \mathbf{m}$ -antenna was 60 meters high and was supported by a rope from the top of the tower. Because of its near field characteristics the antenna created a useful illumination of the tower at a distance of only 100 meters.

This paper will describe in more detail these measurements made on the Kaknäs tower and the test equipment configuration including the $\mathbf{p} \times \mathbf{m}$ antenna.

EMP COUPLING TO SHIPS : ANALYSIS OF DIFFERENT TECHNIQUES

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46500 GRAMAT - FRANCE

EMP coupling assessment with a warship presents some difficulties, basically due to the dimensions of the system and to water. People concerned by these problems had to develop specific tools ; some of them are described in this paper and their performances compared.

The big pulse simulators (like EMPRESS II) are probably the most interesting devices for this application ; but they are very expensive, and they need the implementation of considerable ressources.

Scale model experiments and numerical studies do not need the immobilization of the ship. They remove the problems due to water and they allow to change easily the threat or other parameters.
Even if the precision is limited by the cost (numerical codes) or by the scale factor, even if it can be difficult to reproduce and measure the rise time, these two means give good results : some of them are presented and compared.

The next step consists in the evaluation of the internal transients : the limits of the tools described before induced the development of a CW method.

POSEIDON is the name of the experiment performed by the Centre d'Etudes de Gramat and the CERTEL.

The principle of the experiment (which will be presented in detail) is to sweep the spectrum with a set of different antennae, amplifiers and sensors.
The ship under test (150 m long) is at anchor at 400 m from the emission point. The test is directed from a computer put on board ; a link allows the synchronization between the source on earth and the 5 spectrum analyzers (in the ship) which perform 5 measurements at the same time.
Different steps of signal assessment are necessary to go back to temporal signals.

Some examples of results are given and compared with signals coming from theoretical studies and scale model experiments.

The advantages of this method are numerous : stability of emission source, high dynamic range, low cost, easy moving and implementation.
The main problems come from the long signal assessment (minimum phase), the need of a reference and the spectrum weakness in the low frequencies. Some answers are given.

The conclusion shows the complementarity of all these tools.

A SCALE-MODEL SIMULATOR FOR SYSTEM TESTS

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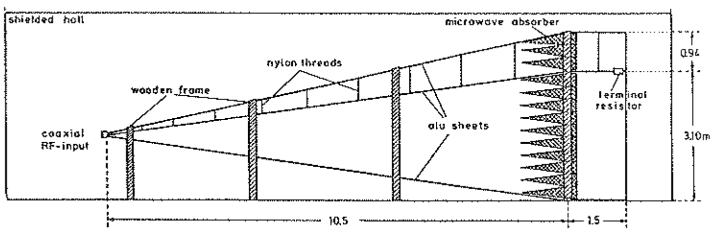
Our institute investigates electromagnetic effects on large structures and systems. For this purpose, we perform calculations with various computer codes (LIAN, NEC-2, MAFIA) as well as measurements with a self-developed field-coupling facility. With this TEM-simulator we perform scale- model measurements on conductive structures and systems.

The facility consists of a 10.5 m long asymmetric triplate transmission line, which widens from some cm at the source pyramidally to 4 m at the end. At low frequencies it is terminated with a network of resistors, at high frequencies a wall of absorbers placed across the output provides a non-reflecting termination. In a test volume of about 2x3x2 m scaled models of long wire antennas, shelters, aircraft etc. down to a scale factor of 1/50 can be tested. In general, we measure the complex transfer functions of the surface current density on the test object, $j(\omega)/E(\omega)$, and of the bulk and short circuit currents on a wire, $I(\omega)/E(\omega)$, in the frequency range between 1 and 2500 MHz. Folding the transfer function with the spectrum of an arbitrary stimulating pulse (NEMP for example) and Fourier transforming the product leads to the response of the system in the time domain.



Since 1985 we have conducted a great variety of tests of rather simple structures such as antennas and cylinders as well as of more complicated objects such as aircraft (1/20 scale-model of planned European fighter J 90 and 1/10 of TORNADO) and a 1/50 scale-model of the German frigate F 122.

In the last years there was an increasing demand for microwave coupling measurements up to the higher GHz-region, so we examined our simulator above the original bandwidth and improved its properties by some simple modifications. At present, we measure surface current densities on a slotted cylinder and the coupling onto wires behind these slots in the frequency range from 10 MHz up to 8 GHz.

SURFACE CURRENT DENSITY INDUCED ON AIRCRAFT ILLUMINATED BY EMP

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ABSTRACT

The surface current density induced on the aircraft illuminated by the nuclear electromagnetic pulse (NEMP) is discussed in this paper. Theoretical and experimental data are presented. The moment method and stick model of the aircraft were used to calculate the induced surface current. The electric field used for the calculation is the double exponential waveform :

$$E(t) = 52\ [\exp(-t/670) - \exp(-t/3.8)] \qquad kV/m$$

the unit of t is ns

The EMP simulator was constructed for the coupling experiment. The scale down Aluminum aircraft was used for this experiment. The length of the fuselage is 6 m, and the radius is 22.6 cm. Induced surface currents on the cylinder(only fuselage without wings) for different azimuth angles (0°, 45°, 90°. 125°, 180°) and different elevations(0.5m, 1.7m, 2.9m, 4.2m, 5.5m) were measured. These surface currents were calculated and compared with experimental results. Both results are pretty agreeable with each other. Surface currents induced on the scale down aircraft were measured and calculated. The peak of the surface current density is from 570 A/m to 1530 A/m. The peak value on the wing is from 210 A/m to 260 A/m. Resonant frequencies induced on the aircraft were also measured and discussed. The main resonant frequency is found from 8.5 MHz to 10.9 MHz for the different length of fuselage and wing, and the wing location with respect to the fuselage. Also, the second resonant frequency of the surface current induced on the aircraft depends on the length of the wing and the location of the wing. If the wing length is very short, the second harmonic will close to three times of main frequency. Results in this paper will be useful for the design of the protector due to the EMP in the aircraft.

MODAL EXCITATION OF A LARGE AIRCRAFT USING MULTIPLE ANTENNAE

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An aircraft is a compound electromagnetic scatterer, having various modes of oscillations, each mode having a characteristic frequency and damping constant. Modal excitation has been been explored extensively by innovative theorists, but has not been demonstrated experimentally in much detail. Modal excitation offers the hardness surveillance community a sophisticated tool of characterizing electromagnetic coupling to aircraft systems for at least two reasons: 1. Low level CW techniques are cheap and easy to implement and 2. Modal excitation reduces the uncertainties due to limited orientation of the aircraft. Results from earlier direct drive and antenna SPEHS (Single Point Excitation for Hardness Surveillance) development efforts suggested that these type of techniques could be used to modally excite an aircraft.

Modal excitation of a large aircraft was demonstrated by attaching electrically short monopole antennae to the aircraft's extremities (nose, tail, and wing tips) and feeding these antennae in-phase or out-of-phase using appropriate transformers and/or power amplifiers. The magnitude and phase of the magnetic fields on the surface of the aircraft was measured with MGL sensors, phase matched fiber optics systems and a computer controlled network analyzer. Measurements were made on the EMP Testbed Aircraft (EMPTAC), which is a Boeing 720 airframe and is similar to the aircraft on which much of the theoretical work was done.

Relatively pure single mode excitation was demonstrated for the lowest frequency modes. The resonances were much broader than those predicted by theory and the mode structure seems to disappear for frequencies greater than four times the lowest resonant frequencies. The resonant frequencies are significantly different than those predicted by theory.

Tuesday AM AP-S, URSI-B D, NEM Session TA03

Room: Grand C *Time*: 0820-1200

Photonic Systems for Antenna Applications

Organizer: Michael L. Van Blaricum, Toyon Research Corp.
Chairs: Michael L. Van Blaricum, Toyon Research Corp.; C. H. Cox III, MIT Lincoln Laboratory

0820* **HIGH PERFORMANCE ANALOG FIBER-OPTIC LINKS for ANTENNA APPLICATIONS**
C. H. Cox III*, MIT Lincoln Laboratory

0900 **A CRITICAL LOOK at PHOTONICS for PHASED ARRAY SYSTEMS**
David D. Curtis*, Robert Mailloux, Rome Laboratory

0920 **REMOTE MULTI-OCTAVE ELECTROMAGNETIC FIELD MEASUREMENTS USING ANALOG FIBER OPTIC LINKS**
S. A. Pappert*, M. H. Berry, S. M. Hart, R. J. Orazi, S. T. Li, Naval Command, Control and Ocean Surveillance Center

0940 **OPTIMIZING ANTENNA DESIGNS WHEN USING INTEGRATED OPTICAL MODULATORS**
Michael L. Van Blaricum*, Michael P. Grace, Toyon Research Corp.; Thomas L. Larry, Toyon Research Corporation

1000 **LUNEBURG LENS ANTENNA with PHOTONIC SENSORS**
Don Hilliard*, Dean Mensa, Naval Air Warfare Center

1020 **HISTORY and the STATE of the ART of BULK MODULATORS for EM MEASUREMENTS**
Jerry C. Wyss*, Colorado Sensor Technology, Inc.

1040 **A SMALL WIDEBAND ANTENNA PRINTED on the SAME LiNbO3 SUBSTRATE AS the INTEGRATED OPTICAL MODULATOR**
Nobuo Kuwabara*, Tsuyoshi Ideguchi, NTT Telecommunications Networks Labs; Ryuichi Kobayashi, University of Electro Communications

1100 **WAVE-COUPLED W-BAND LiNbO3 MACH-ZEHNDER MODULATOR**
William B. Bridges*, Finbar T. Sheehy, California Institute of Technology; James H. Schaffner, Hughes Aircraft Company

1120 **PHOTONIC ELECTROMAGNETIC FIELD PROBES**
Motohisa Kanda*, Keith D. Masterson, David R. Novotny, NIST

1140 **SENSITIVITY ISSUES in PHOTONIC SENSOR SYSTEM DESIGN**
Gail T. Flesher*, General Research Corp.

HIGH PERFORMANCE ANALOG FIBER-OPTIC LINKS FOR ANTENNA APPLICATIONS

C. H. Cox III

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Optical fibers offer the potential for removing an often significant perturbation source from both the measurement of antenna patterns as well as the conveyance of RF to and from antennas. Unfortunately, this advantage has been masked by limitations in the RF-to-optical and optical-to-RF conversion processes needed to couple the RF into and out of the fiber, respectively. For example, these conversion processes typically result in a zero-length link transducer loss of 20 to 60 dB and noise figures of 30 to 70 dB. Recent progress in our understanding of the impact of various device parameters on link performance has permitted the design of links with net RF gain and noise figures as low as 6 dB.

In this talk simple analytic lumped-element small-signal models will be reviewed for the two most common link implementations: direct modulation of a diode laser, as shown in Fig. 1(a), and external modulation of a laser using a Mach-Zehnder integrated-optic modulator, as shown in Fig. 1(b). Although both modulation methods result in an intensity modulated optical carrier, the modeling reveals there are fundamental differences between the two in the dependance of various link parameters on device parameters. For example, Fig. 2(a) contrasts the RF gain and Fig. 2(b) shows the noise figure for both types of modulation versus average laser optical power. Analytical and experimental data show that passive impedance matching can be used to reduce loss and even achieve net RF gain in directly modulated links. A similar analysis for externally modulated links shows that the optical power, modulator sensitivity and impedance matching can be optimized to achieve net gain.

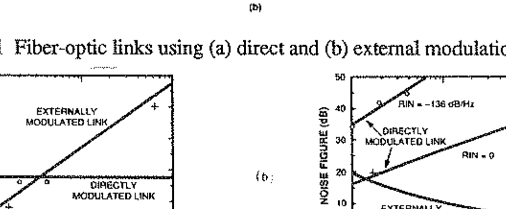

Fig. 1 Fiber-optic links using (a) direct and (b) external modulation

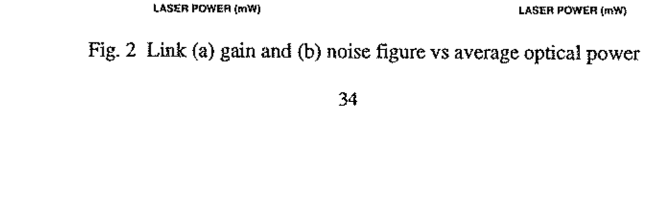

Fig. 2 Link (a) gain and (b) noise figure vs average optical power

A CRITICAL LOOK AT PHOTONICS FOR PHASED ARRAY SYSTEMS

David D. Curtis* and Robert J. Mailloux

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Rome Laboratory

Recent progress in photonics has focussed attention on control of phased array systems. Assessments range between the most avid proponents' optimistic view that the technology will soon replace most microwave analog scanning networks, to the pessimistic view that it will be too lossy, too costly, and too complex. This paper is an attempt to view photonic array control from the perspective of the array designer, to assess its potential in light of current array technology, and to suggest necessary developments.

Modern phased array technology provides accurate array control at relatively low cost. Passive analog systems cost hundreds of dollars per element, and with some added cost penalty can provide RF signals with a degree or two of phase error and tenths of a dB of amplitude error, as required for low sidelobe radiation. At higher frequencies efficiency can become a limitation, but solid state modules can improve efficiency, provide more power at the array, and improved signal to noise on receive. Solid state module arrays have traditionally been more expensive, but the costs are now competitive for some applications. Receive arrays using digital beamforming can provide the ultimate in low sidelobes and adaptively optimized pattern control.

Photonics has a difficult role to play against this existing technology, but brings some advantages that assure it a place in array control. In digital control signal distribution and RF power distribution, one can expect to see early applications of photonic technology. Control signal distribution complicates present day arrays, and is a relatively simple function to do photonically. RF signal distribution using photonics can, in principle, have the required accuracy, but losses in modulation and detection will require its use with solid state modules. The cost and reduction in dynamic range may limit this application for some systems. The use of photonics to provide time delay has great potential for wide band arrays, but is not without competition from digital beamforming systems, and does not readily admit to adaptive control. This paper addresses the state of developments in these areas, and highlights aspects of photonics research deemed critical to the deployment of photonics in array antenna systems.

REMOTE MULTI-OCTAVE ELECTROMAGNETIC FIELD MEASUREMENTS USING ANALOG FIBER OPTIC LINKS

S.A. Pappert*, M.H. Berry, S.M. Hart, R.J. Orazi, and S.T. Li

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Broadband electromagnetic field detection and monitoring systems have been investigated in the 30 MHz - 18 GHz frequency range. To minimize the intrusiveness of these field monitoring probes, fiber optic and electro-optic techniques have been employed to transmit the detected broadband information to a remote processing station. These short-haul (< 1 km) wideband fiber optic links possess no electrical or optical amplifiers to boost the detected antenna signal which increases the importance of constructing low noise figure transmission links. Both directly modulated (current modulation of injection laser diode) and externally modulated (voltage modulation of optical waveguide modulator) wideband optical systems have been developed.

Results of anechoic chamber tests of several electromagnetic field detection systems will be presented. The performance of a 2 - 18 GHz externally modulated system will be presented which consists of a broadband cavity-backed spiral antenna, an optical waveguide modulator, a 1.32 μm Nd:YAG solid state laser, single-mode optical fiber, and a high-speed photodiode. Operation with both III-V semiconductor based and lithium niobate based optical waveguide modulators have been investigated and compared for the externally modulated system. An rms electric field sensitivity of 15 μV/m and a spurious free dynamic range of 102 dB in a 1 Hz resolution bandwidth have been measured with this 2 - 18 GHz field detection system. The performance of a 30 MHz - 500 MHz directly modulated system will also be presented which consists of a broadband VHF/UHF antenna, a laser diode, single-mode optical fiber, and a photodiode. For each field sensing system, the frequency response, electromagnetic field sensitivity, dynamic range, as well as environmental stability are reported. The advantages and disadvantages of both the directly modulated and externally modulated electro-optic field detection systems will be discussed.

OPTIMIZING ANTENNA DESIGNS WHEN USING INTEGRATED OPTICAL MODULATORS

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The use of integrated-optical Mach-Zehnder interferometers (MZI) as the pick-up or modulation devices in optical antenna and sensor links allows a new set of options for the antenna designer to consider. Externally modulated optical links are inherently very broad-band. The bandwidth of optically based antenna links are therefore, usually limited by the antenna and matching network. In addition, the input impedance of integrated-optical modulators is capacitive with a small real part of a few Ohms. The modulator responds to the voltage induced across this capacitive reactance. Therefore, the design of antennas and matching networks to connect to external optical modulator links should not be limited to conventional or classical design considerations where typical 50 Ohms loads are used.

In this paper, we will investigate techniques for designing gain and bandwidth of a complete optical antenna link by optimizing antenna and matching network designs as a function of the sensitivity of the MZI. The newly written SCINW thin-wire antenna optimization code is used as the design tool to optimize the antenna and the matching network parameters. The FOLSIM (Fiber Optical Link SIMulator) code was used to predict the overall optical link gain, noise-figure, and dynamic range resulting from the optimized antenna and matching network designs when nominal optical device parameters are used.

Several typical antenna and matching network examples will be presented. It will be shown that the use of the optical modulator as a pick-up device will allow higher gain for a smaller effective aperture in cases where narrow band performance is desired. In addition, we will discuss approaches to broad-banding the antenna to take advantage of the optical link bandwidth.

LUNEBURG LENS ANTENNA WITH PHOTONIC SENSORS

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Standard approaches to sensing electromagnetic fields employ metallic antennas attached to transmission lines which couple the antenna to a receiver. A major disadvantage of this method is the perturbation in the measured field caused by the conducting materials used for the antenna and transmission lines. In addition, transmission lines are typically subject to attenuation and dispersion which limit the cable length at microwave frequencies, and are vulnerable to EMI and EMP sources. This paper describes a concept that eliminates these disadvantages by implementing an all-dielectric field sensing system composed of a Luneburg lens antenna and photonic sensors (U.S. Navy Patent Pending). The system measures the frequency, amplitude, phase, and angle-of-arrival of the fields. Tests have been conducted on a prototype version of this system. The photonic sensor used in these proof-of-concept tests was provided to the Navy by Colorado Sensor Technology, Inc. The Luneburg lens used in the tests was provided to the Navy by Rozendal Associates.

The Luneburg lens is a spherically-shaped, broad-band dielectic device that focuses an incident planar electromagnetic wave entering one side of the lens onto a spot on the opposite side of the lens (R.K. Luneburg, "Mathematical Theory of Optics", University of California Press, 1964, pp. 182-188). Photonic sensors are coupled with the Luneburg lens by positioning the electro-optic modulators on the focal surface of the lens. The field captured by the lens are focused onto the corresponding modulator, thus enhancing the sensitivity of the system by a factor proportional to the focusing gain of the lens. The angle-of-arrival of the fields can be determined by noting which sensors are most strongly modulated. Electro-optic modulators can be placed over the entire surface of the lens to provide 4π steradian coverage, Aperture blockage, that would occur with metal antennas is reduced because the modulators covering the lens surface on the side of field incidence are effectively transparent to the field thus allowing fields to penetrate into the lens and focus onto modulators on the opposite side.

Examples of applications for use of this system include: probing the fields of anechoic chambers; probing in areas of potential biological hazards; and as receiving antennas not susceptible to lightning, e.g, as a replacement to the parabolic satellite television antenna.

History and the State of the Art of Bulk Modulators for EM Measurements

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Abstract.

Eighty-four years ago, F. Pockels demonstrated the existence of the linear electrooptic effect in bulk crystals using an applied electric field. For the last forty-six years, various experimenters have been exploiting this effect to modulate light at progressively higher frequencies. In most of these applications, an electric signal is amplified and applied directly to a bulk crystal, with the main goal of efficiently modulating the light.

For the last fifteen years, a number of researchers have been applying the bulk crystal Pockels effect to construct antennas that can efficiently receive an electromagnetic (EM) signal without greatly perturbing the signal being measured. This paper will review the design parameters of such systems with particular emphasis on how these designs relate to the antenna characteristics. After briefly discussing some of the present problems in performing EM measurements with non-photonic techniques, this article will show how photonic sensors may solve some of these problems. In one application a system will be shown that has short metallic dipole antennas directly coupled to the bulk crystals. This configuration will be shown to have a minimum sensitivity of 1.7 mV/m per $Hz^{1/2}$ and a frequency bandwidth of 2.0 GHz.

Eliminating the dipoles and using the bulk crystal as the antenna element by itself, a more compact, ruggedized, practical system has been built which has a minimum sensitivity of 40 V/m per $Hz^{1/2}$, and a frequency bandwidth of greater than 2.0 GHz. Such a system has many applications including fast rise-time EMP measurements.

Wave-Coupled W-Band $LiNbO_3$ Mach-Zehnder Modulator

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Electro-optic modulators commonly use lithium niobate ($LiNbO_3$) as the substrate because of its high electro-optic coefficient. However, $LiNbO_3$ is dispersive, so the optical and electrical signals have different propagation times along the modulator electrodes. To prevent averaging of the signal in the modulator at high signal frequencies, the electrodes must be short, which gives low sensitivity.

We previously reported a method of cascading many short modulator electrodes, with the modulating signal coupled to the electrodes by antennas which were illuminated so that each electrode was driven in the proper phase. This makes it possible to construct sensitive modulators at high signal frequencies. In addition, since the modulator is radiatively coupled it is suited to waveguide-based systems and field sensing applications. We demonstrated X-band (10 GHz) and V-band (60 GHz) prototype phase-modulators at 633 nm optical wavelength. Our demonstration was restricted to phase-modulation because we used dipole antenna elements, and there was no convenient way to apply DC bias to the elements. A Mach-Zehnder amplitude modulator needs DC bias in order to operate in its linear region.

More recently we designed Mach-Zehnder amplitude modulators for W-band operation (94 GHz), at 1.3 μm optical wavelength. These modulators use bow-tie antennas, which are relatively insensitive to DC bias connections made to the ends of the antenna elements. The bow-ties should also give a greater bandwidth than the dipole antennas. The design and performance of these new modulators will be presented.

PHOTONIC ELECTROMAGNETIC FIELD PROBES

Motohisha Kanda, Keith D. Masterson, and David R. Novotny

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ABSTRACT

We describe optically sensed probes designed to accurately measure electromagnetic fields. The probes use passive electro-optic modulators of Pockels cell or integrated optics designs to transfer the electromagnetic signal to an optical carrier propagating in an a fiber optic link. This approach eliminates the need for active components or power sources in the probe head. It minimizes the distortion of the field being measured and is immune to EMI pickup on the lines leading to the signal processing electronics. Fiber optic systems are also capable of bandwidths up 100 GHz, while preserving both signal amplitude and phase over lines 100's of meters long. We describe an approach to modeling system performance using cascaded transfer functions. We also describe several probe systems that have been fabricated at NIST over the last few years. They include an isotropic probe consisting of three orthogonal dipoles, a probe for EMP measurements up to 200 kV/m, a probe using an integrated optics modulator for frequencies to above 3 GHz, and a probe to simultaneously measure both the electric and magnetic fields and their relative phases. The latter holds the potential of determining the Poynting vector in a plane wave, or of measuring the radiation emitted over the entire 4π steradians from a device placed at the center of three orthogonal, concentric loops. Field strengths down about 10 $\mu V\ m^{-1}\ Hz^{-½}$ are detectible using these techniques. Well designed photonic probes with passive electro-optic modulators have linear dynamic ranges of above 70 dB.

SENSITIVITY ISSUES IN PHOTONIC SENSOR SYSTEM DESIGN

by

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Abstract

Use of photonic technology in antenna or sensor systems is receiving close scrutiny for various applications where some aspect of photonic signal handling is superior to the equivalent rf technique. At the same time, the other aspects of photonic usage must not be allowed to substantially degrade other system performance goals. This paper addresses the important issue of sensitivity of photonic rf sensors or antenna elements compared to the usual non-photonic types, when no rf preamplifier is used.

The use of photonic techniques bring in new signal responsivity factors and new noise sources. Their effects on S/N ratio through the parameters of the overall system are presented. A number of different modulation techniques will be presented. The photonics sensor or photonic probe will be used as a comparison system because of its advantageous lack of need for metal coaxial cable for carrying signals. Coaxial cable causes reflections and field re-distribution to occur, highly perturbing the fields being measured. Use of optical fiber for signal transmission can eliminate most of this disturbance.

The more sensitive systems currently require optical phase or frequency control. To avoid this increase in complexity, the parameters to be targeted for improvement through research will be highlighted. Chip integration of the feedback control functions may also prove to be a feasible goal as optical components improve in performance and control aspects.

Photonic rf sensitivity is steadily approaching non-photonic sensitivity and is adequate for many applications now. Future system design will use photonic techniques as the advantages begin to outweigh the diminishing disadvantages.

Tuesday AM1 URSI-E, NEM Session TA12

Room: Columbus I/J *Time*: 0900-0940

EMP Environments and Extrapolation

Chair: W. Radasky, Metatech Corporation

0900 **A COMPLETE EMP ENVIRONMENT GENERATED by HIGH-ALTITUDE NUCLEAR BURSTS**
K.-D. Leuthauser*, Fraunhofer Institut fur Naturwissenschaftlich-Technische Trendanalysen (INT)

0920 **EXTRAPOLATION of EMP RESPONSES: an EXPERIMENTAL and ANALYTICAL STUDY**
C. L. Gardner*, S. Kashyap, M. R. Lauzon, J. S. Seregelyi, Defence Research Establishment Ottawa; J. J. A. Klaasen, TNO Physics and Electronics Laboratory

A COMPLETE EMP ENVIRONMENT GENERATED BY HIGH-ALTITUDE NUCLEAR BURSTS

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ABSTRACT

Very few papers are available in the open literature on high-altitude nuclear EMP fields offering detailed quantitative results for the whole variety of weapon related input parameters (i. e. gamma yield, energy and pulses shape) and scenario oriented quantities (i. e. height of burst, observer location with regard to Ground Zero).

Recently, the EXEMP code developed by the author was extensively employed for systematic variation of the above mentioned parameters. The present version of the code is self-consistent, i. e. solves the equation of motion of the Compton electrons in the presence of EMP generated electric and magnetic fields. Moreover, it comprises the following features

- exact energy-angle correlation for the Compton electrons (Klein-Nishina)
- exact ionization loss (Bethe-Bloch equation)
- inclusion of multiple ionization scattering effects (obliquity) in equation of motion
- electron mobility and avalanching dependent on air density-scaled electric fields
- ionization time lag for build-up of conductivity
- dipole earth magnetic field
- curved earth surface

The basic approximation is still the high frequency or outgoing wave approximation of the Maxwell equations in retarded time which are thus reduced to ordinary differential equations.

Equations of motion of Compton electrons, electron density rate equations and Maxwell equations are solved numerically by means of a fourth order Runge-Kutta algorithm.

The influence of the various input parameters on the incident electromagnetic fields will be extensively discussed, including 'smile-face' diagrams and plots showing pulse width, power per unit area and polarization dependent on observer location.

Extrapolation of EMP Responses:
An Experimental and Analytical Study

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and

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ABSTRACT

Recently Klaasen (J.J.A.Klaasen, DREO Report 1076, May, 1991) has proposed a time-domain extrapolation technique based on the singularity expansion method (SEM). In the method developed by Klaasen, the experimentally measured EMP response of a system is extrapolated to that which would have been measured if the incident field had been a true double-exponential (Bell Laboratories) waveform.

In recent years, the double-exponential waveform has been criticised as being unrealistic at early times because the first derivative of this waveform is discontinuous at the onset of the pulse. This discontinuity is inconsistent with the physics of the fission process and the generation of prompt gamma rays during a nuclear explosion. To overcome this difficulty, other waveforms have been proposed of which the "new NATO" pulse (NATO EMP Engineering Practices Handbook, File No. 1460-3, 1989) is one of the most commonly used. Depending on the type of simulator used for experimental measurement and whether the equipment being measured is intended to be airborne or ground based, it may also be necessary to include or remove the effects of ground reflections during the extrapolation process.

In this paper we examine the extension of the method developed by Klaasen to allow extrapolation to more complicated incident waveforms such as the new NATO curve. We will present the results of various analytical studies that have been carried out and, in addition, the results of experimental studies exploring the extrapolation of measured responses from one input waveform to another.

Tuesday AM2 URSI-E, NEM Session TA16

Room: Columbus I/J *Time:* 1000-1200

EMP Interaction

Chairs: K. S. H. Lee, Donald P. McLemore, Kaman Sciences Corporation

1000 **ON the COUPLING of MICROWAVE RADIATION to WIRE STRUCTURES**
C. D. Taylor*, Mississippi State University; Charles W. Harrison, Jr.,

1020 **A SPECTRAL DOMAIN APPROACH to ELECTROMAGNETIC COUPLING THROUGH APERTURES**
A. B. Kouki*, A. Khebir, R. Mittra, University of Illinois, Urbana-Champaign

1040 **ELECTROMAGNETIC COUPLING THROUGH a ROW of AIRCRAFT WINDOWS for FREQUENCIES LESS THAN 100 MHZ**
Lothar O. Hoeft*, Joseph S. Hofstra, Ronald Karaskiewicz, BDM International, Inc.

1100 **FREMP COUPLING THROUGH an AIRCRAFT WINDOW**
Lothar O. Hoeft, Joseph S. Hofstra*, Ronald Karaskiewicz, BDM International, Inc.

1120 **RESPONSE of TYPICAL AIRCRAFT ANTENNNAE to FAST RISETIME EMP**
Lothar O. Hoeft*, David E. Thomas, Joseph S. Hofstra, Robert L. Hutchins, Ronald Karaskiewicz, BDM International, Inc.

1140 **ATTENUATING EM WAVE PENETRATION INTO a RESONANT CAVITY by AUGMENTING MULTIPLE MONOPOLES**
Gu Zeji*, Beijing Broadcasting Istitute

ON THE COUPLING OF MICROWAVE RADIATION TO WIRE STRUCTURES

by

Clayborne D. Taylor
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ABSTRACT

The general aspects of the interaction of wire structures with microwave radiation are considered. Receiving antenna theory is used for structures whose characteristic dimension is a few wavelengths or less. And transmission line theory is used for electrically long wire configurations.

A simple procedure is presented for bounding the response of wire structures that are not electrically long. This is achieved through using the receiving cross section. The maximum receiving cross section and radiation resistance are presented for obtaining the bounds on the general responses of a few canonical configurations - the center-loaded dipole, the circular loop antenna, the impedance loaded monopole, and the transmission line antenna. This formulation is valid until the structure dimensions approach several wavelengths.

The analysis of electrically long wire structures is accomplished by using transmission line considerations. Results are obtained for a terminated single wire oriented parallel to a nearby ground plane and for a two-wire transmission line. In both cases plane wave illumination is considered. Both simple formulas and data from a numerical analysis are provided. It is shown by comparing results from a general numerical solution to results obtained from transmission line theory that the TEM mode current is a suitable approximation for the wire current with line separations up to and exceeding a wavelength.

Measured results are also discussed. Coupling data for both shielded and unshielded wire configurations are analyzed. Finally, coupling to general wire configurations inside enclosures is discussed. This requires that coherence effects be considered.

A SPECTRAL DOMAIN APPROACH TO ELECTROMAGNETIC COUPLING TROUGH APERTURES

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The problem of electromagnetic coupling through apertures in perfectly conducting screens has received considerable attention ever since the early days of the electromagnetic era. Kirchhoff in 1891 used a scalar approach that was based on Huygen's principle and Green's theorem and concentrated on the high-frequency range where the aperture field was assumed to be essentially the same as the incident field. On the other hand, Lord Rayleigh in 1987, with his calculation of the fields in the vicinity of the aperture, postulated a wavelength approaching infinity, and thus provided the low-frequency counterpart to Kirchhoff's work.

During 1970s, when significant advances in computer technology started taking place, more insight into the aperture coupling problem was gained through the application of numerical techniques (C.M. Butler & K. R. Umashankar, Radio Sci., vol. 11, pp. 611-619, 1976) and (C. M. Butler, Y. Rahmat-Samii & R. Mittra, IEEE Trans. Antennas Propagat., vol. AP-26, pp. 82-93, 1978). The approach used was based on an integro-differential equation formulation in the spatial domain and involved the decomposition of the original problem into equivalent half-spaces. The spectral domain method is used in a similar fashion (i.e., with equivalent half-spaces) but results instead in a pure integral equation that is solved in the transform domain. In addition to being more appealing in the formulation process, the spectral domain technique also covers a wider class of structures than its spatial domain counterpart. In particular the inclusion of dielectric layers on either side of the slot can easily be incorporated in the analysis.

Results for the aperture field distribution in slots of variable sizes are obtained and compared to previously published results by Butler *et al.* The extension of the present formulation to other slot structures will be discussed.

ELECTROMAGNETIC COUPLING THROUGH A ROW OF AIRCRAFT WINDOWS FOR FREQUENCIES LESS THAN 100 MHZ

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Albuquerque, NM 87106
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The electromagnetic coupling through the 29 forward windows of a commercial aircraft was measured as part of program to estimate the internal EMP coupling into large aircraft. A parallel plate transmission line was installed on the surface of the aircraft over the windows. A computer controlled network analyzer and two MGL magnetic field sensors allowed measurement of the magnetic field coupling between the surface of the aircraft and interior points. Replacing the interior sensor with a current probe allowed transfer functions to be measured between the surface of the aircraft and representative cable bundles. Measurements were made between 10 kHz and 100 MHz.

For frequencies up until 60 MHz, the magnetic field transfer function was independent of frequency. These measurements showed that the magnetic field from this array of apertures decreased as $1/r^2$. One meter from the window centerline, the magnetic field transfer function was 45 dB below the surface magnetic field. Off axis test points were lower, as would be expected.

The transfer function between the aircraft fuselage and the current on vertical cables near the windows was about -90 dB for frequencies between 0.5 and 10 MHz. For 6 kA of fuselage current, the coupled currents due to the windows would be about 200 mA.

This initial electromagnetic coupling survey allowed the electromagnetic vulnerability of the aircraft to be estimated on the basis of measured transfer functions. This reduced the uncertainties in the internal coupling calculations.

FREMP COUPLING THROUGH AN AIRCRAFT WINDOW

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In order to obtain a better understanding of how fast risetime electromagnetic pulse (FREMP) waveforms couple through aircraft windows and to nearby wiring, a controlled experiment was conducted on a large commercial aircraft and on a surrogate aperture that had the same dimensions as an aircraft window. This aperture was excited with a tangential electric field produced by a 1 ns risetime 10 kV square wave pulser and a horn type exciter placed against the aircraft surface. All measurements were made with appropriate time domain instrumentation.

These measurements demonstrated that the aperture affected the exciting pulse in a number of ways. One of the principal effects was that the aperture reduced the fall time of the transmitted pulse. For an aperture the size of a passenger window, the width of the transmitted pulse was about equal to the risetime. The second effect demonstrated by these measurements was that the peak amplitude of the field inside of the aperture along a line normal to the surface decreased as $1/r^3$. This suggests that for the time regimes of the excitation pulse, the electromagnetically excited aperture acted like a dipole.

Quantitative measurements were made of the FREMP coupling to cables in the vicinity of the window. The amplitude of the current pulse on these cables decreased rapidly at locations on the cable only a fraction of a meter away from the aperture, indicating a loss mechanism was involved. The most likely loss mechanism was radiation and/or a dispersive propagation medium on the surface of the cable.

RESPONSE OF TYPICAL AIRCRAFT ANTENNAE TO FAST RISETIME EMP

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Deliberate antennae, by their very nature, collect and transmit to the system large transients when exposed to an electromagnetic pulse (EMP). Except for a few HF antennae, most of the deliberate antennae on an aircraft are designed to operate above 100 MHz. Most antennae behave like a derivative sensor (response proportional to frequency until resonance). Thus, while these antennae may have a nominal response to the relatively slow risetime of the "traditional double exponential" pulse, their response to a faster risetime pulse could be significantly higher. Because of questions concerning the applicability and availability of analytical models, it was decided to measure the response of all of the antennae from an aircraft and calculate the transient that resulted from exposure to fast risetime EMP.

The voltage response of 15 antennae was characterized by installing them in the wall of a Transverse Electromagnetic (TEM) cell and measuring the voltage response from 500 kHz to 1 GHz using a computer controlled network analyzer.

The transient response was estimated by calculating the response to the Heaviside unit step function, fitting the unit step function frequency domain response with damped sine waves using a Prony technique, summing the damped sines to get the unit step time time domain response, and obtaining the Bell Labs time domain response by convolving with the time derivative of the double exponential surface electric field or obtaining the full amplitude unit step response by multiplying by twice the incident field.

The two waveforms were selected in order to bound the problem. The "traditional double exponential" pulse was selected because it represented a well known waveform and thus served as a point of departure. The Heaviside unit step function was selected because it represented the worst possible waveform. Two types of stimulus surface electric fields were used for the calculations: Twice the incident field and twice the incident field plus the scattered field due to the aircraft response.

These experimental and calculational studies showed that the response of the antenna to the incident field was much more significant (by almost an order of magnitude) than the response to scattered surface electric field of the aircraft. Thus a good estimate of the antenna response could be obtained by using twice the incident field as the forcing function.

Sensitivity studies carried out by varying the number of poles used to fit the frequency domain response showed that the exact form of the response was relatively unimportant in estimating the peak voltage response of the antenna to FREMP. Thus future studies can use simplified models with increased confidence.

This study showed that transient voltages as high as a few tens of kilovolts could appear at the antenna terminals when the aircraft is exposed to a typical Fast Risetime EMP (FREMP).

Analysis of the measured antenna responses with respect to their physical dimensions showed that a reasonably good estimate of the antenna's transfer function could be obtained from its overall physical dimensions.

ATTENNUATING EM WAVE PENETRATING INTO A RESONANT CAVITY BY AUGMENTING MULTIPLE MONOPOLES

Gu Zeji
Department of Radio Engineering, Beijing Broadcasting Institute

It has been found that multiple monopoles which symmetrically straddle the two sides of a slot can greatly reduce EM wave coupling into a resonant cavity. It is demonstrated by moment methods that under the resonant condition, the maximum field amplitude in the cavity is reduced from 85 times without monopoles to 10^{-2} times with monopoles compared with that of incident wave, and the penetration power is attenuated by 10^{-6} times compared with that when the monopoles are not present.

When we study the effect of a strong EM pulse produced by nuclear explosion or lightning on electric equipment or when we study EM shielding and EM compatibility, the phenomenon we often see is EM coupling into a cavity through a slot. Of particular interest is the maximum field amplitude in the slot and inside the cavity exclosure under resonant conditions. D.B. Seidal (IEEE Trans., AP-30, No. 4, 1982) and David K. Cheng (IEEE Trans., MTT-26, 914, 1978) have analyzed the problem. To date, only undertaking theoretical analysis of the problem has been carried out. It does not appear that anyone has attempted to find an efficient approach to solve the problem. The significance of this paper is in having found an efficient approach by which the field inside the resonsant cavity and EM coupling to the resonant cavity can be reduced greatly. Therefore, the shielding effect due to the resonance can be eliminated. From Maxwell' equations and by introducing the boundary conditions, we first establish exact integral equations which consider the effect of the monopole length, the slot length and width, the mutual distance between monopoles, the distance from the bottom of the monopole to the center line of the slot, the thickness of the conducting screen and the wall loss. Then with the help of computer, we obtain the electric currents on the monopoles, magnetic currents on the slot, the field inside the cavity and EM wave coupling power. Further, we obtain the optimum configuration by which the EM coupling is the smallest. The maximum number of monopoles we augment with is 12.

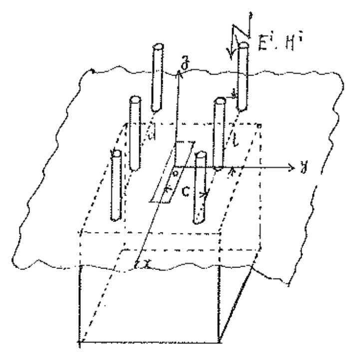
We conclude:

1. If the length l and the distance d are given, the smaller the distance c, the larger the attenuation is obtained. (See figure).

2. There is an optimum length l corresponding to the given distance c and d in which the attenuation is the largest. Also there is an optimum distance d corresponding to the given distance c and length l.

3. The larger the distance c, the shorter the resonant length l is needed, in which the attenuation is the largest.

4. Increasing the number of monopoles does not increase the attenuation. We obtain large attenuation using only 2 monopoles.



Tuesday PM1 URSI-A E, NEM Session TP12

Room: Columbus I/J *Time:* 1320-1500

High Power Electromagnetics Instrumentation

Chair: I. N. Mindel, IIT Research Institute

1320 **ACTIVE SENSORS : HIGH BAND, DYNAMIC and SENSITIVITY INSTRUMENTATION for PROGRESSIVE NEMP and HPM TESTS and EMC**
Gregoire Eumurian*, Fabrizio Pampalone, THOMSON-CSF/DSE

1340 **THE CERENKOV RESPONSE of LUCITE and QUARTZ to GAMMA RADIATION**
F. A. du Chaffaut*, D. Croteau, Centre d'etudes de Bruyeres le Chatel

1400 **DEVELOPMENT of a PROTOTYPE, HIGH SENSITIVITY, WIDEBAND ANALOG FIBER-OPTIC LINK**
Eduardo Saravia*, InterScience Inc.; Bruce T. Benwell, U. S. Army Laboratory Command

1420 **EFFECT of INDUCTIVE COUPLING DEVICES on COUPLED WAVEFORMS**
Charles E. Goldblum*, James L. Press, Ed Damerau, Moshe Netzer, R&B Enterprises

1440 **SWEPT FREQUENCY SINGLE POINT EXCITATION TECHNIQUE for MEASURING the SHIELDING of AIRCRAFT**
Lothar O. Hoeft*, BDM International, Inc.; Donald P. McLemore, Bruce Burton, Stan Kokorowski, Kaman Sciences Corporation; John Pratt, William D. Prather, Phillips Laboratory

ACTIVE SENSORS : HIGH BAND, DYNAMIC AND SENSITIVITY INSTRUMENTATION FOR PROGRESSIVE NEMP AND HPM TESTS AND EMC

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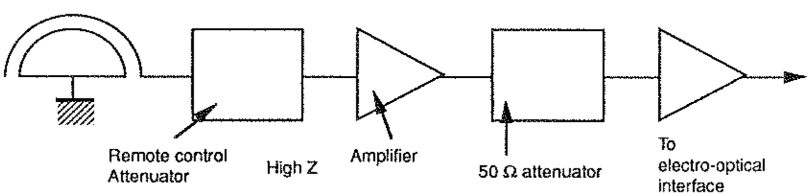
NEMP, EMC and HPM tests require instrumentation with a very broadband ranging from a few kHz to several GHz. Conventional sensors, passive sensors, cover this frequency band. However their large size and lesser sensitivity, requiring electro-magnetic fields at very high levels, do not allow tests on small objects and can only be used at high field levels approaching qualification levels.

Conversely, active sensors, measuring a few centimeters, are able to provide a sensitivity that is almost a thousand times higher ; thereby, enabling test at low levels and gradual rise to the qualification level. This type of test offers the advantages of not being destructive and of costing less than conventional tests. We describe instrumentation based on the use of active sensors for NEMP and EMC tests. The most advanced level of work enables extending this concept to include 1.5 GHz with instantaneous dynamic range > 60 dB for field levels ranging from 50 mV/m to over 1 MV/m. We also show evidence of the feasibility of very broadband active photonic sensors for microwave reseach at a few tens of GHz.



TYPICAL E FIELD NON DERIVATIVE ACTIVE SENSOR

CERENKOV RESPONSE OF LUCITE AND QUARTZ TO Γ RADIATION

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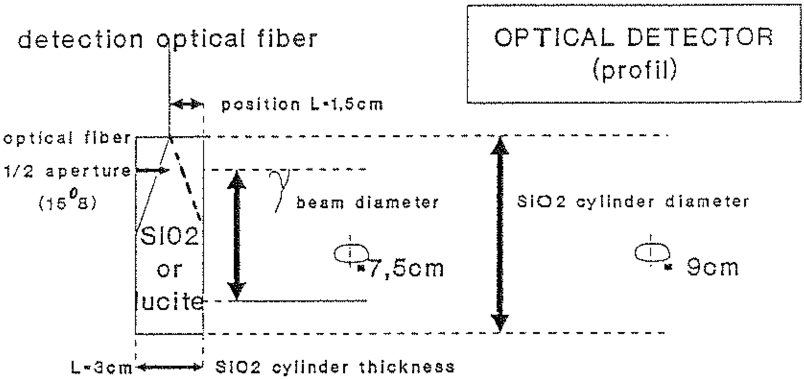
D.Croteau

We have tried to elaborate a relevant theory for evaluating the effectiveness of Lucite and Quartz as CERENKOV materials for "all optical fast "gamma" detectors.We study the theoritical response of such materials to gamma radiations from 0.5 to 10 Mev.The detection of "CERENKOV" light is done with an optical fiber.The following picture shows treated problem geometry.



The topic of this study is the response of the sensor itself We suppose the optical fiber protected enough in order to get no variation in the transmission factor coming from a direct effect from gamma radiation on the fiber.

We are interested in the number of "cerenkov" photons created upon the absorption of a gamma ray of energy Eγ.So we take in consideration: photoelectric effect,pair production,compton effect,and we assume a single scattering event for the "γ" radiation.secondary electrons and Bremstrahlung during the stopping of the primary electron are not studied.
We compute sucessevely :

the electron ranges in SiO2 and Lucite detector
the detection of "CERENKOV" light in an optical fiber
the response of this system versus the "γ" radiation energy.

The path of electrons is studied with the aid of "MOLIERE theory and the computation of electron ranges is done with a MONTE-CARLO method.Electron ways can be traced with a specific graphical program
The hard problem of "CERENKOV" photons collection by optical fiber is solved by a geometrical method.

Finally we compare our theoritical results with these of J.E.DOYLE and W.C.DICKINSON (:UCRL-7032 ,1962).

DEVELOPMENT OF A PROTOTYPE, HIGH SENSITIVITY, WIDEBAND ANALOG FIBER-OPTIC LINK

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Although digital transmission over fiber-optic links is now common, the ability to handle analog signals with arbitrary modulation in photonic systems is only now being developed. With the anticipated advanced high-altitude electromagnetic pulse (HEMP) simulators, there is now the need for a high-sensitivity, wideband, miniature transmitter/data link that can be used to isolate the output signal of electric and magnetic field sensors (during transmission to remotely located instrumentation) from the intense electromagnetic (EM) environment produced over the simulators test volume.

In cooperation with Harry Diamond Laboratories (HDL), InterScience, Inc., is developing an analog optical link based on the direct modulation of an ultrahigh-speed miniature diode laser with the rf signal generated by an EM sensor. The link specifications are an operational bandwidth from 10 KHz to 2 GHz, a sensitivity of 20 μV, and a dynamic range of 40 dB. A small size (<7.5 cm^3) is necessary to minimize the perturbation to the EM fields being measured. The specifications of this link are well beyond those of present commercially wideband optical links. More specifically, the system consists of an InGaAsP miniature laser diode as a source, a single-mode optical fiber, and an InGaAsP PIN photodiode. Pre-amplification of the input signal is needed to drive the laser diode and cover the entire dynamic range, i.e., input signals from 20 μV at the tangential noise level to 2 mV at the 1 dB compression point. Other important features of the laser transmitter include bias and network matching of the rf input, monitoring and automatic control of the dc power to keep the laser bias optical power constant and a built-in calibration capability. A fully operational breadboard prototype system was assembled and subjected to extensive testing, both as individual components and as an integrated system. The results have demonstrated that the proposed analog optical link can be fully implemented with present technology to meet all performance requirements.

EFFECT OF INDUCTIVE COUPLING DEVICES ON COUPLED WAVEFORMS

Dr. Charles E. Goldblum, James L. Press, Ed Damerau, Moshe Netzer
R & B Enterprises, 20 Clipper Rd. W. Conshohocken PA 19428

This paper uses a unique technique for determining the transfer function of a coupling device as a function of frequency and load. At the present time, typical test procedures for EMP and lightning testing as well as some recent developments in CW radiated susceptibility testing utilize a calibration procedure consisting of a coupling device and a generator driving a known low inductive load. After calibration on this know load, the coupler is placed round the cable under test and the injection onto the cable is performed while monitoring the current and/or voltages. The output of the generator is then increased until either the calibrated setting is achieved or the required voltage/current is reached. Due to the differences between the known load and the cable under test, the waveforms may be radically different. These differences are typically caused by cable impedances and the complex load impedance of the unit under test. The technique presented here will allow the test planner or test engineer to predetermine the shape of the waveform on the cable and determine the optimal waveform norms that are applicable to the unit under test. Comparison will be made between a theoretical waveform and data taken in the laboratory. Typical EMP and lightning waveforms will be used such as double exponential, damped sine wave and trapezoidal. A discussion of various standards and test procedures will be presented detailing the importance of this work on future test methods and standards.

This technique for predeterming the coupled waveform will consist of the following algorithm:

1. A fast Fouier transform (FFT) is performed on the signal waveform to determine its frequency content.

2. A measurement of the scattering parameters of the coupling device (S_{11}, S_{12}, S_{22}, and S_{21}) is performed. These measurements will be made using a vector network analyzer (HP8753C) and the coupling device as a two port network.

3. Transformation of the scattering parameters into a set of ABCD parameters typically used in impedance measurements.

4. The transmission line is then represented as a two port network and its S parameters are measured and transformed into the ABCD space.

5. An analysis is performed using existing software to determine the transfer function of the coupling device, transmission line, generator, and load impedances.

6. Convoluting the signal spectrum derived in step #1 with the transfer function derived in step #5. This will determine the frequency response of the coupled and measured waveform.

7. Perform an inverse Fourier transform on the convoluted spectrum calculated in step #6 to retrieve the time domain waveform of the coupled waveform.

Data will be presented showing the transfer function for various loads ranging from 50 ohms to 10 kilohms. The paper will discuss the advantages of this technique and discuss its impact on future specification and standards for conducted susceptibility testing. With the support of data taken using standard measurement techniques, such as signal generators, oscilloscopes and spectrum analyzers, the paper will illustrate the effectiveness of this technique for determining waveform norms that are essential for the engineer who is attempting to design transient protection devices for electronic devices that are required to meet various conducted susceptibility requirements. The paper will then conclude with various examples of the utility of this new technique for determing coupled waveform characteristics.

SWEPT FREQUENCY SINGLE POINT EXCITATION TECHNIQUE FOR MEASURING THE SHIELDING OF AIRCRAFT

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John Pratt and William D. Prather
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(505)846-0416

A swept frequency single point excitation technique was recently demonstrated which show great promise for measuring the exterior field to cable current transfer functions of well shielded aircraft without using special facilities. Measurements were made for frequencies between 100 kHz and 200 MHz using a computer controlled network analyzer, a 15 W power amplifier, fiber optic links and appropriate sensors.

These measurements showed that good signal-to-noise ratios could be maintained when measuring currents on the cores of well shielded cables using only 15 W of power. Reproducibility of the measurements was good up to 80 or 100 MHz. Above these frequencies, the magnetic fields on the surface of the aircraft depended to some extent on the ground return configuration. Above 80 MHz, the magnetic fields on the surface of the aircraft and the current coupled to the cable cores showed evidence of several broad resonances. However, when the cable core measurements were referenced to the surface magnetic fields, these broad resonances were removed.

Comparison of the peak current induced by the EMP simulator to the current transfer function measured using the swept frequency single point excitation showed that the two techniques displayed the same trends, however, there was some scatter in the data (about a factor of 2 or 3). The peak current response obtained using the EMP simulator appeared to be directly proportional to the magnitude of the current transfer function at 2.7 MHz. At 80 MHz, the peak current appeared to be proportional to square root of transfer function.

The effect of inserting degradations in the cables and apertures could be seen in certain cases. In most cases, the significant coupling path was not the cable shield at the test point. Therefore, degrading the shield did not significantly increase the coupling.

The significance of this work is that it demonstrated that transfer functions between the surface magnetic fields on the fuselage and currents on second level conductors (wires within shielded cables) were able to be measured over a wide frequency range with simple equipment and without special facilities.

Tuesday PM2 URSI-E, NEM Session TP15

Room: Columbus I/J *Time*: 1520-1640

Device Characteristics

Chair: J. P. Castillo, R & D Associates

1520 **USING the R2SPG to CHARACTERIZE and EVALUATE EMP UPSET THRESHOLDS**
Lothar O. Hoeft*, William H. Cordova, Ronald Karaskiewicz, Gerald A. McArthur, Bradley Spalding, Joseph S. Hofstra, BDM International, Inc.

1540 **FLASH X-RAY EFFECTS on MMIC**
Daniel C. Yang*, TRW Electronic Systems Group; K. Vu, T. Lunn, E. Rezek, L. Fletcher, TRW Inc.

1600 **MODELING SATURABLE MAGNETICS for EMP ASSESSMENTS**
Joseph Miletich*, Llewellyn Jones, William Slauson, Raytheon Company

1620 **USING ESD DAMAGE DATA to PREDICT EMP FAILURE THROUGH the WUNSCH-BELL MODEL**
Thomas L. Fowler*, Arthur J. Wan, Texas Instruments, Radiation Effects

USING THE R^2SPG TO CHARACTERIZE AND EVALUATE EMP UPSET THRESHOLDS

Lothar O. Hoeft*, William H. Cordova, Ronald J. Karaskiewicz, Gerald A. McArthur, Bradley Spalding and Joseph S. Hofstra
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The Repetitive Random Square-wave Pulse Generator (R^2SPG) was designed and built as one of a series of tools available for S/V engineers to use in system hardening programs. It is a small, simple, battery operated pulser that produces broadband fast rise-time (2.5 ns), controllable, high-amplitude transients at an average rate of 30 pulses per second. Its small size allows the same equipment to be used in the laboratory and on operational systems. It was designed to be an "electronic hammer" that could be used to excite the cable systems of a aircraft, ship, or ground system while they are installed using peak currents up to those associated with specification level EMP plus a safety factor of approximately 20 (26 dB). The R^2SPG, in itself, does not replace full-scale testing, as global illumination is not provided. However, in situations where complex digital upset testing is required, or where full-scale system tests cannot be done (for reasons such as system unavailability, schedule or cost), the R^2SPG provides a good alternative technique for electromagnetically stressing hardened systems. Because the R^2SPG produces a broadband transient, it excites the cable under test at its resonant frequencies. Thus the coupling is similar to EMP field to cable coupling. Comparison measurements using the EMP Testbed Aircraft (EMPTAC), demonstrated that the R^2SPG produces cable currents that are similar to those produced by EMP simulators.

Initially, the usefulness of the R^2SPG for upset testing was demonstrated on an AT class digital computer. This was followed by upset testing on a number of operational systems, including: a large digitally controlled communication system, a data display sub-system, and two radar sets. The first radar used 1960's analog technology retrofitted with digital computers. The second radar set was of 1970's vintage and made more extensive use of digital computers.

The small size of the R^2SPG made it convenient to take it to the operational systems for a short but meaningful test. The upset threshold was quickly established and its severity or impact on mission performance was evaluated. If necessary, temporary hardening fixes or procedural work-arounds could be developed on the spot and test. In addition, confidence was gained in the conservative nature of the original damage assessment.

If the upset threshold was within the limits of the test program and the capabilities of the R^2SPG, significant upsets generally required 3 to 10 A, even in unhardened systems. "Snow" on visual displays occurred at smaller currents. As expected, more modern systems had lower thresholds and more frequent upsets than older systems with less digital technology. None of the systems were damaged by the test. This tentatively confirms the statement that "upset occurs before damage."

FLASH X-RAY EFFECTS ON MMIC

D. C. Yang*, K. Vu, T. Lunn, E. Rezek and L. Fletcher

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A study was made on dose rate radiation effects for four different types of MMIC processing technologies including 0.25 μm ion implanted GaAs MESFET, 0.25 μm MBE GaAs MESFET, 0.2 μm pseudomorphic AlGaAs/InGaAs HEMT and GaAs/AlGaAs HBT. The exposures were made with the Vulcan Flash X-Ray machine which has a half-max pulse width of 45 nanoseconds. All four types of MMICs were tested from $1x10^{10}$ rads/sec to approximately $1x10^{12}$ rads/sec. The operating frequency range of the circuits tested is from 3 GHz to 35 GHz. All circuits passed the radiation test without failure. A description of the test circuits and test results are presented as follows.

The HBT test circuit is an amplifier divider which consists of 138 transistors, and takes an input signal from 3.0 to 4.5 GHz and perform a divide-by-4 operation. Two samples were tested. The first was exposed up to $8.7x10^{11}$ rads/sec. The disturbances lasted from approximately 1 microsecond at low level to slightly less than 2 microseconds at high level. A second sample was also tested and displayed similar result.

A two-stage 6 to 10 GHz low noise amplifier was used as the 0.5 μm ion-implant MESFET test circuit. Each stage consists of a 0.5 x 300 μm transistor. It exhibits 15 dB gain and 5 dB noise figure. The test sample was exposed up to $9.5x10^{11}$ rads/sec and the results showed a complete initial dropout and returned to normal CW operation in 15 to 20 microseconds over the entire test range.

The 0.25 μm MBE MESFET test circuits is a 35 GHz two-stage balanced power amplifier with two 0.25 x 150 μm and two 0.25 x 300 μm MESFETs. It has 7 dB gain and +20 dBm output power. The test circuit was exposed up to $8.7x10^{11}$ rads/sec. It was observed that after an initial complete dropout, recovery to normal levels occurs in approximately 2 microseconds.

For 0.2 μm pseudomorphic HEMT a 26 to 40 GHz two stage balanced low noise amplifier consisting of four 0.2 x 100 μm HEMT devices was used as the test circuit. It has a nominal gain of 15 dB and 4 dB noise figure. It was exposed up to $1x10^{12}$ rads/sec and the recovery time was approximately 2 to 3 microseconds.

The flash X-Ray radiation hardness characteristics of four different types of GaAs MMICs were investigated. Good results were obtained on all of them. Further studies on total dose and neutron radiation effects are necessary to fully utilize the MMICs in the radiation environments.

MODELING SATURABLE MAGNETICS FOR EMP ASSESSMENTS

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EMP protection circuits often utilize inductors with ferromagnetic cores. Recent assessments have shown the necessity of evaluating saturation of filters and inductors when assessing EMP protection circuits. Current versions of circuit simulation codes include models for non-linear magnetics. These models allow the EMP engineer to accurately model blocking inductors and EMI power line filters.

The response of the following typical hardening designs have been simulated using the Jiles-Atherton model in PSPICE®: an inductor isolating a large MOV from downstream clamping components, an EMI power line filter, and a small pin filter. With the Jiles-Atherton model, it is possible to model the B-H hysteresis curve, effects of DC bias current and frequency permeability roll-off.

The case of an inductor being used to isolate downstream components from an MOV is examined in detail. The Jiles-Atherton model values with resulting B-H curves are given for typical molypermalloy powder cores. The SPICE circuit simulation is presented for two cases, with clamping components and with power filters downstream. It is shown that saturation effects of downstream filters is possible even when the isolating inductor does not saturate. The results show the importance of frequency and damping factor in the EMP pin specification and the importance of looking at the entire system when conducting an EMP assessment.

EMI power line filters are too often ignored or treated very cursorily in standard EMP assessments. It is shown that with the Jiles-Atherton model it is possible to accurately predict the EMP transient response of power line filters. Test responses of filters to typical damped sinusoids are compared to model predictions. In addition, standard CW insertion loss curves are compared to SPICE model predictions. Other examples, such as typical pin filters are examined to show the utility of this approach of modeling magnetics in SPICE. The results of the assessments show that it is possible and in many cases important to model the magnetics in typical protection designs.

USING ESD DAMAGE DATA TO PREDICT EMP FAILURE THROUGH THE WUNSCH-BELL MODEL

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Abstract

The Wunsch-Bell component damage model is a widely-used method of assessing the damage thresholds of semiconductor devices. Testing of components for Wunsch-Bell parameters is usually performed using a pulse generator which delivers a contant power to the device under test. Sources which may damage the device during operation in a circuit deliver a time-varying power to the component and cannot be directly related to the Wunsch-Bell parameters.

In the early 1970's, work was performed by Miletta, Peden, and Tasca to relate arbitrary power v.s. time waveforms to the time invariant power pulses used to generate the Wunsch-Bell characterization data. The work performed in this paper is a continuation of that effort. Electro-Static Discharge (ESD) damage threshold information has been related to EMP damage. This allows the system EMP analyst to take advantage of any ESD characterization data which may be available on components.

During the 1980's, Mil-Std-883 and Mil-Std-750 were revised to include an ESD hardening assessment test. The ESD waveform is similar in form to the Mil-Std-461C RS05 pulse, and can be represented with a similar double-exponential approximation. Competition among Integrated Circuit (IC) manufacturers has resulted in continuous improvement in ESD performance for new product lines, but the older product lines have remained essentially unchanged. ESD performance data for the newer ICs is generally available from most IC manufacturers and is often included in the data sheets.

The method described in this paper applies classical linear systems theory to the problem. First, the thermal impulse response of the device is obtained from the ESD damage data with the convolution integral. Next, the impulse response is represented in the frequency domain using the Fourier transform. Linear systems theory predicts that the convolution of the impulse response with arbitrary forcing functions gives the temperature rise of the IC junction (Wunsch-Bell theory). In the frequency domain, this convolution simplifies to a point-by-point multiplication. The EMP-induced forcing function is treated as a variable and determined through power spectrum integration of the respective Fourier transforms. In this manner, an EMP threat equivalent to the known ESD damage level is derived.

With a few simplifying assumptions, the results can be tabulated and used to evaluate system damage at the component level.

Wednesday PM AP-S, URSI-A B E, NEM Session WP01

Room: Grand E *Time*: 1320-1700

Transient Radar

Organizers: Carl E. Baum, Phillips Laboratory; Ivan J. LaHaie, Environmental Research Inst. of Mich.
Chairs: Carl E. Baum, Phillips Laboratory; Ivan J. LaHaie, Environmental Research Inst. of Mich.

1320 **STATUS of ULTRAWIDEBAND (UWB) RADAR and ITS TECHNOLOGY**
Merrill Skolnik*, Naval Research Laboratory

1340 **APERTURE EFFICIENCIES for IRAs**
Carl E. Baum*, Phillips Laboratory

1400 **ANALYSIS of the IMPULSIVE RADIATING ANTENNA**
Everett G. Farr*, EMA Inc.

1420 **OVERVIEW of the HDL IMPULSE SYNTHETIC APERTURE RADAR**
John W. McCorkle*, U. S. Army Laboratory Command

1440 **SELECTED SEA CLUTTER and TARGET MEASUREMENTS with a 0.2-1.0 GHZ ULTRA-WIDEBAND RADAR**
Michael A. Pollock, Vincent P. Pusateri, Thomas E. Tice, Robert J. Dinger*, Naval Ocean Systems Center

1500 **Break**

1520 **ULTRA-WIDE BANDWIDTH, MULTI-DERIVATIVE RADAR SYSTEMS**
Richard W. Ziolkowski*, University of Arizona

1540 **TRANSIENT RADAR for TARGET IDENTIFICATION and DETECTION**
K. M. Chen*, Dennis P. Nyquist, E. Rothwell, P. Ilavarasan, J. Ross, Michigan State University

1600 **BAYESIAN PROBABILTY THEORY APPLIED to the PROBLEM of RADAR TARGET DISCRIMINATION**
Lloyd S. Riggs*, Auburn University; C. Ray Smith, AMSMI-RD-AS-RA

1620 **A REVIEW of CURRENT GROUND PENETRATING RADAR CONCEPTS**
Jonathan D. Young, M. Poirier, Leon Peters, Jr.*, The Ohio State University

1640 **PANEL DISCUSSION on FUTURE of TRANSIENT RADAR (CHAIR: M. SKOLNIK)**

STATUS OF ULTRAWIDEBAND (UWB) RADAR AND ITS TECHNOLOGY

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An ultrawideband radar (which is somewhat arbitrarily defined as one with a relative bandwidth greater than about 25%) is of current interest because of its successful application for ground probing radar and the challenge of working in an area where the commonly invoked assumption that signals are narrowband is not necessarily valid. It is also of interest because of the importance of bandwidth in many radar applications. This paper describes some of the major differences between UWB and narrowband radar; such as the transient nature of radiation and scattering, the need to account for dispersive effects when propagation is over a wide frequency range (especially at low elevation angles), the effects of UWB in the Fresnel region, the limitations of the narrowband assumption widely used in signal processing theory, the complexity of signal processing when the target cannot be considered as a point source, the time-dependent nature of sea scatter when viewed with high spatial resolution, and the opportunity to process the actual UWB RF signal waveform rather than its envelope. Examples of some of these differences are given, including the radiation of a single cycle from a dipole (which is relatively broadband) and the nature of the Fresnel region when a single cycle is radiated (both examples are due to S. Samaddar). The current status of UWB radar technology for transmitters, antennas, and signal processing is briefly reviewed. The role of the laser-actuated semiconductor switch transmitter is discussed and compared with more conventional tube technology and with solid state modules. The possibility of analog or digital signal processing for area MTI to detect moving targets in clutter is also reviewed.

APERTURE EFFICIENCIES FOR IRAs

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In a previous paper (C.E. Baum, Radiation of Impulse-Like Transient Fields, XXIII URSI General Assembly, Prague, 1990, p. 277) it was shown that a suitable antenna for use as part of an impulse radar consists of a paraboloidal reflector fed by conical TEM wave launcher with termination impedances at the junction with the reflector edge. With a step-like (fast rising) wave on the feed, the radiated field has a narrow impulsive part with time integral (or area of waveform) proportional to 1/r times the integral of the electric field over the effective aperture illuminated by the reflector. The antenna pattern is reinterpreted in time domain in the form of pulse width or amplitude as a function of angle off the center of the beam.

This paper considers the characteristics of the aperture shape and size for launching the impulsive portion of approximate impulse-radiating-antenna (IRA) waveforms. Using complex-variable techniques the electric field on the aperture plane (early time) is assumed to have the distribution of a TEM plane wave (inhomogeneous) on the aperture and is formulated as a complex field given by the derivative of the complex potential with respect to the complex coordinate (two dimensional). The surface integral is converted to a contour integral around the aperture for ease in evaluation. This is used to define appropriate characteristic lengths for the aperture which can be maximized for best impulsive operation. Some convenient shapes (e.g. circular) are evaluated in closed form which can be directly used in the design of such antennas. The aperture optimization is applied to both TEM horns and TEM-fed reflectors, which are shown to have complementary structures on the aperture plane.

ANALYSIS OF THE IMPULSE RADIATING ANTENNA

Everett G. Farr

There has been a growing interest in the radiation of broadband pulses of electromagnetic energy. One candidate for such an antenna is the Impulse Radiating Antenna (IRA) (C.E. Baum, Sensor and Simulation Notes 321, 327, and 328). The purpose of this paper is to analyze further the properties of the IRA, and to provide a basis for comparison to other candidate antennas.

A diagram of the IRA is shown in Figure 1. It consists of a paraboloidal reflector fed by a 400-Ω spherical transmission line. Our design called for a 1.2 m dish with a F/D ratio of 0.4. At the junction of the feed and the dish are 2 200-Ω terminations that provide an approximately matched load at low frequencies. The spherical transmission line feed is a variant of a Balanced Transmission-line Wave (BTW) feed (E.G. Farr, IEEE Trans. Electmag. Compat. Vol. 33-2, pp. 105-112, 1991). The BTW feed provides a measure of directionality at low frequencies, and reduces late-time ringing of the radiated waveform.

The analysis proceeds along a two-pronged approach. At low frequencies, the structure is analyzed with the Method of Moments (MoM) using the Numerical Electromagnetics code. At high frequencies, we used Geometrical Optics (GO). It is shown that the GO results overlap the MoM results over a certain portion of bandwidth. After obtaining frequency domain results, one can drive the antenna with a step-function like time domain waveform in order to see the radiated waveform in the far field. We chose an inverse double exponential with a 10-90% risetime of 250 ps. and time to decay to 10% of the peak of 500 ns.

A graph of the radiated field on axis is shown in Figure 2. Note that for a step function input, we expect an impulse function to be radiated, with artifacts both before and after the peak. This is what is seen in Figure 2. Furthermore, we know exactly the size and shape of the artifact on the leading edge of the waveform, so we can gauge the accuracy of the calculations. Preliminary calculations suggest that the BTW feed successfully reduces the ringing in an IRA. Since that is one of the important requirements for successful Ultra Wideband systems, it appears that the IRA will be a leading candidate for the antenna of such a system.

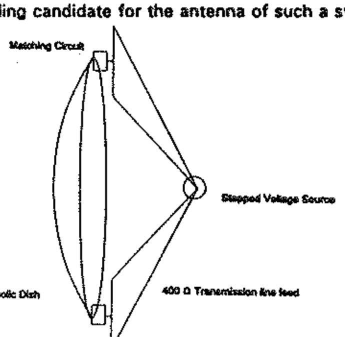

Figure 1. The Impulse Radiating Antenna.

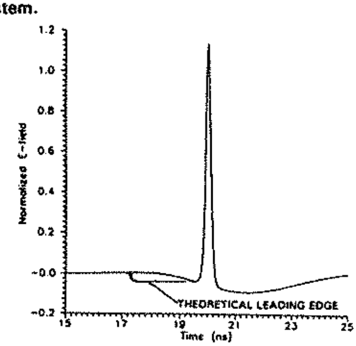

Figure 2. Waveform Radiated on Boresight.

OVERVIEW OF THE HDL IMPULSE SYNTHETIC APERTURE RADAR

JOHN W. MCCORKLE
U.S. ARMY HARRY DIAMOND LABORATORIES

Historically, the relative bandwidth of radars has been sufficiently small that a target's echo is adequately modeled by a single number, σ, the Radar Cross Section (RCS) -- usually given in square meters. As a corollary, historically, radar systems have not measured target ringing. In the ultra-wide bandwidth (UWB) case where $.5 < \Delta F/F_0 < 2$, however, a single number does not adequately describe a target's RCS. First, σ is a function of frequency. The well known plot of the RCS of a sphere showing Rayleigh, resonant, and optical regions is an example. Second, in addition to the magnitude characteristic plotted, there is also a phase characteristic. These two frequency-domain characteristics can also be represented as a time domain signature containing a ringing or resonant response. In either case -- time domain or frequency domain -- the plots can be referred to as the impulse response of the target.

The process of obtaining images of the reflectivity or density of target areas that are rotating and translating with respect to a sensor such as a monostatic or bistatic radar, a sonar, or an x-ray CAT scanner has been studied for the past 40 years. Dale A. Ausherman , Adam Kozma, Jack L. Walker, Harrison M. Jones, and Enrico C. Poggio ("Developments in Radar Imaging" IEEE Trans. Aerosp. Electron. Syst. AES-20, No.5, pp. 363-400: Jul. 1984) give an excellent review of the work done in this area. Until now, however, implementation and study of image formation processing has been limited to isotropic point scatterers. Most radar targets, however, are anisotropic, resonant, and dispersive scatterers. Treatment of these cases becomes important when the sensor spectrum covers the Rayleigh, resonant, and optical regions of a family of targets. For example, discrimination between scatterers can be based on the unique signature of each target - but only if the information in the signature is preserved in the image formation process. Inclusion of anisotropic features become even more important when the aperture covers large angles.

This paper describes an impulse radar built on a railroad track on top of the main building at the U. S. Army's Harry Diamond Laboratories facility in Adelphi Maryland. The radar operates over a Ultra-Wide Bandwidth (UWB) of 50-1000 MHz and is fully polarimetric. Coherence is maintained across the aperture by a coherent-on-receive system. The pulse repetition interval (PRI) is jittered by a code with a spike autocorrolation. A 384 foot railroad track is used to collect data over a synthetic aperture. The radar includes a 480 MFLOP array processor that is used to do pulse-to-pulse interference filtering followed by a backprojection focusing algorithm. Since the bandwidth of the radar is greater than that of real targets, both the range resolution and azimuthal resolution are a constrained by the target scattering characteristics rather than the radar. Azimuthal resolution is further degraded since the target RCS is not constant for all positions on the synthetic aperture. The backprojection algorithm works in the time domain. It is modified to preserve natural resonance energy reflected by targets. Measurements to be carried out by the radar include clutter backscatter, foliage penetration loss, foliage penetration group delay, signatures of dispersive targets in the presence of clutter, and signatures of anisotropic targets in clutter.

SELECTED SEA CLUTTER AND TARGET MEASUREMENTS WITH A 0.2-1.0 GHZ ULTRA-WIDEBAND RADAR

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Impulse generators that can produce very short pulses (less than one nanosecond) and a very high peak powers (a few gigawatts) have been developed in recent years for the simulation of electromagnetic pulse (EMP) effects. The availability of such sources has naturally led radar designers to consider their use in radar systems: Instead of generating a high range resolution waveform by conventional pulse compression means, the notion is to simply transmit the ultra-short pulse in a brute force manner to achieve the desired range resolution. The advantages proposed for such an ultra-wideband (UWB) impulse radar range from better detection of low flying aircraft to exploitation of nonlinear target scattering effects. To explore the potential of UWB radar for over-the-ocean surveillance applications, we began a program at the Naval Ocean Systems Center (NOSC) to design and assemble an UWB radar in 1991 at a test site located along the Pacific Ocean near San Diego. The source generated a pulse with a 0.5-nsec pulsewidth and a 0.2-nsec rise time, yielding a waveform with energy concentrated in the 0.2 - 1.0 GHz portion of the spectrum. Incidence angles to the ocean of 0.35 to 7.0 degs were possible. In this paper we will describe the radar and a few of the first measurements with it. In particular, we present the first calibrated measurements ever reported of sea clutter made over a bandwidth of 0.2-1.0 GHz.

Ultra-Wide Bandwidth, Multi-Derivative Radar Systems

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The characteristics of the beams generated by ultra-wide bandwidth electromagnetic systems are central to their practical applications. These characteristics include the rate of beam divergence, the beam intensity, and the energy efficiency. Analytical bounds on the characteristics of beams generated by an arbitrary pulse-driven array have been derived and supported with numerical calculations. (R. W. Ziolkowski, "Localized Wave physics and engineering", Phys. Rev. A, vol. 44(6), 3960-3984 (1991); R. W. Ziolkowski, "Properties of Electromagnetic Beams Generated by Ultra-Wide Bandwidth Pulse-Driven Arrays", to appear in IEEE Trans. Antennas and Propagat., 1992) These bounds will be briefly reviewed; they extend the meaning of near-field distances or diffraction lengths to the situation where the array driving functions can be broad-bandwidth signals. Particular attention will be given to transmitting and receiving array systems which consist of elements that are not large in comparison to the shortest wavelength of significance contained in the signals driving them. The output signals of such systems are multiple time derivatives of the input driving functions. They constitute multi-derivative beam systems whose coherence properties are degraded more slowly by diffraction than lower-order systems. The bounds define the extent of these extended near-field enhancements.

It has also been shown that for certain measures of performance involving these beam characteristics, a localized wave pulse-driven array can outperform similar continuous-wave-driven arrays. A new type of array is required to realize these localized wave effects - one that has independently addressible elements. The enhanced localization effects are intimately coupled to the proper spatial distribution of broad-bandwidth signals driving the array; i.e., by controlling not only the amplitudes, but also the frequency spectra of the pulses driving the array. These enhancements have been verified with an array of ultrasound transducers in water. (R. W. Ziolkowski and D. K. Lewis, "Verification of the localized-wave transmission effect", J. Appl. Phys., vol. 68, pp. 6083-6086, 1990) Possible photo-conductive switch based realizations of these independently addressible arrays and multiple derivative systems will be discussed.

A brief discussion of a preliminary analysis of the potential applicability of multi-derivative, localized wave arrays to radar and to other remote sensing systems will be given. It will include the effects of having a target within the extended near-field region of a localized wave array. Comparisons between a localized wave pulse driven array system and the corresponding conventional continuous wave system will be used to illustrate these results.

TRANSIENT RADAR FOR TARGET IDENTIFICATION AND DETECTION

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A radar system using narrow interrogating EM pulses can provide capabilities of target identification and detection. When a target is illuminated by a narrow EM pulse, the scattered response from the target consists of an early-time response and a late-time response. The late-time response has been utilized to discriminate and identify the target based on the E-pulse (Extinction-pulse) and the S-pulse (Single-mode extraction pulse) techniques. These techniques are aspect-independent and their basic principles have been developed at Michigan State University. Our present effort on these techniques is to study the effectiveness of these techniques in the presence of sea clutter and noise.

We have initiated a study on the utilization of the early-time response of the target for target identification. The early-time response of a target consists of a series of sharp peaks representing specular reflections from discontinuities of the target structure. The locations and amplitudes of these peaks can be determined from the measured early-time response through a theoretical technique. The target is then identified by correlating its early-time response with that stored for a group of targets for various aspect angles. This procedure necessitates the storage of vast amounts of data. We have developed a method for reducing the amount of stored data based on the observed behavior of the early-time response. The scheme of using the early-time response has an advantage of high energy content but a disadvantage of aspect dependency leading to the need for predetermining the target's aspect angle.

We have also initiated a study to develop effective schemes to enhance the target response without increasing the noise and clutter levels for the purpose of target detection using narrow EM pulses. Possible schemes include the waveform shaping of interrogating pulses and coherent response processing utilizing the relative motion of the target against the background.

Bayesian Probability Theory Applied to the Problem of Radar Target Discrimination

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In this paper the task of discriminating among a set of N known targets based on their radar returns is viewed as a problem of information processing, calling for a full application of probability theory. Two distinct problem areas will be investigated.

In the first, Bayesian probability theory is used to derive an expression for an enhanced discrimination waveform which, in the two target case, maximizes the log odds in favor of one target over the other. Target transfer functions are computed in the resonance region (target linear dimensions on the order of a wavelength) using the singularity expansion method. Numerical results are provided which show that best discrimination, in the simple two target case, occurs when the incident waveform has its energy concentrated near the frequency where the difference in the impulse response of the two targets reaches a maximum. Changes in the enhanced discrimination waveform with target aspect will be discussed.

In the second part of this presentation probability theory is employed to discriminate among a set of targets based on their high-range-resolution (HRR) radar returns. An expression for the back-scattered field from a triangular-patch model of a perfectly conducting radar target (without apertures) is derived using the usual physical optics (PO) approximation for the currents induced on the target by the incident field. The frequency domain expression for the back-scattered far field is inverse Fourier transformed to obtain the target's HRR radar return. Example calculations show that for the four target case the Bayesian algorithm identifies the unknown target correctly greater than 90% of the time for signal-to-noise ratios as low as 2 (3 dB).

A REVIEW OF CURRENT GROUND PENETRATING RADAR CONCEPTS

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Department of Electrical Engineering

Ground Penetrating Radars (GPR) have been used for shallow penetration for a number of years and a session at the Society of Exploratory Geophysicists in 1991 has discussed some of their applications. The usual GPR uses a base band pulse, sampling system and some type of antenna. Given a computer controlled system, then a time (or range) dependent gain can be included by inserting a preamplifier and a computer controlled attenuator.

The crucial element in the system, however, is the antenna which is usually some form of a heavily loaded linear antenna or separate transmit and receive linear antennas. It is essential that the ringing of such an antenna be reduced so that it does not obscure the low level scattered field of interest. Separate transmit-receive pairs using either a crossed dipole or a "bistatic" antenna are used to reduce the direct coupling from the transmitter to the receiver. A novel antenna designated as the Active Isolation Antenna has recently been put in practice. This is a "bistatic" antenna with two transmitting antennas of opposite polarity excited so that they cancel at the receive antenna. This has proven more successful than the crossed dipole or the usual bistatic antenna for detecting buried pipe. Results obtained using a mobile system by a Geophysical colleague, Prof. Daniels, using the bistatic configuration are also to be presented.

A focussed beam antenna, a reflector with a transmission line feed, has been used to detect a buried mine as has the Active Isolation Antenna. This is a preliminary version of possible transient array antennas. Several suggestions are to be put forth for such focussed arrays. Results obtained using the above antennas are to be presented along with some simplified signal processing.

Wednesday PM AP-S, URSI-A B D E K, NEM Session WP05

Room: Columbus I/J *Time*: 1320-1700

Computers in Electromagnetics Education

Organizers: R. E. Collin, Case Western Reserve University; Magdy F. Iskander, University of Utah
Chairs: R. E. Collin, Case Western Reserve University; Magdy F. Iskander, University of Utah

1320 **INTEGRATION of the PERSONAL COMPUTER INTO UNDERGRADUATE ELECTROMAGNETICS COURSE**
Warren L. Stutzman*, Virginia Polytechnic Inst. & State Univ.

1340 **COMPUTER AIDS in CHEMICAL ENGINEERING EDUCATION- an ASSESSMENT of CACHE - 1971-1991**
Warren D. Seider*, University of Pennsylvania

1400 **THE USE and IMPACT of VISUAL ELECTROMAGNETICS SOFTWARE in the CLASSROOM**
R. W. Cole*, Curtis Brune, University of California, Davis

1420 **COMPUTER SIMULATIONS in the CHEMICAL ENGINEERING LABORATORY**
P. K. Andersen*, R. G. Squires, G. V. Reklaitis, Purdue University

1440 **INTERACTIVE COMPUTER MODULES for UNDERGRADUATE CHEMICAL ENGINEERING INSTRUCTION**
H. Scott Fogler, Susan M. Montgomery*, The University of Michigan

1500 **Break**

1520 **PROGRESS in COMPUTATIONAL ELECTROMAGNETIC MODELING for EM COURSEWARE: a PERSONAL PERSPECTIVE at PENN STATE**
Karl S. Kunz*, The Pennnsylvania State University

1540 **REFLECTIONS on CAEME SOFTWARE and NEW DEVELOPMENTS TOWARDS SOFTWARE IMPLEMENTATION in CLASSROOM TEACHING**
Magdy F. Iskander*, University of Utah

1600 **INTEGRAL EQUATIONS in ELECTROMAGNETICS for UNDERGRADUATES**
Chalmers M. Butler*, Clemson University

1620* **DISCUSSION/DEMONSTRATIONS**

COMPUTER AIDS IN CHEMICAL ENGINEERING EDUCATION -- AN ASSESSMENT OF CACHE -- 1971-1991

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Abstract

Since its inception in 1971, the CACHE Corporation has concentrated on promoting cooperation among universities, industry, and government in the development and distribution of computer-related and/or technology-based educational aids for the chemical engineering profession. This article assesses the success of several projects designed to provide aids for individual courses, as well as for a broader segment of the curriculum. The projects include: (1) the provision of 125 computer assignments for the core courses, (2) the preparation of teaching materials for, and the distribution of, Monsanto's FLOWTRAN program for use in the design courses, (3) the preparation of PC modules for many courses, leading to the Michigan project on the Development of Innovative Engineers and the Washington project on Graphical Computer Aids, for fluid flow and reaction, in the design of chemical reactors, and (4) the development of the MICROCACHE courseware delivery system. Also considered are the CACHE recommendations concerning the minimum requirements for computing in the undergraduate curriculum, presented to the AIChE Education and Accreditation Committee. The CACHE Corporation has facilitated several research conferences, the impact of which is assessed.

THE USE AND IMPACT OF VISUAL ELECTROMAGNETICS SOFTWARE IN THE CLASSROOM

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Learning Skills Center
University of California, Davis

Abstract

Electromagnetic radiation, involving non-local retarded solutions to Maxwell's equations, has long been difficult to teach and frustrating to learn. It often takes years of study to be able to conceptually understand a solution without using the powerful mathematics of Maxwell's theory. This steep learning curve is a major contribution to the decrease in the number of students choosing electromagnetics as a career. In response to this state of affairs, we have developed software that runs on a MacIntosh microcomputer and helps students visualize the fields and electromagnetic effects. The software consists of a field simulator that maps the electric, scalar potential, vector potential, and magnetic fields around distributions of point charges. The charges may be static, moving, and accelerating. It allows radiation patterns to be simulated from the charge distributions. It supports contour, pseudo-color, and fieldline maps of the fields. In addition, there are several HyperCard tutorials that accompany the simulation program, and span an introductory course in electromagnetics. The HyperCard tutorials point out useful features in classic field problems and relate the field maps to the fundamental laws of electricity and magnetism. They feature animated field sequences and animated equations. After a brief description of the software, we will present a video tape showing it being used in the introductory calculus physics class at the University of California, Davis, both by the instructor in lecture, and by the students in classroom discussion sections. You will be able to see how students are interacting with the software. Finally, results on how the software has affected student performance will be presented. We will analyze the impact computer instruction has had on the students.

Computer Simulations in the Chemical Engineering Laboratory

P. K. Andersen
Department of Freshman Engineering

R. G. Squires and G. V. Reklaitis
School of Chemical Engineering

Purdue University
West Lafayette, IN

A number of computer-based modules have been developed for the senior chemical engineering here at Purdue University. Each module comprises a sophisticated simulation and a videotaped "plant tour" of an actual chemical plant, produced with the technical assistance of an industrial sponsor. To date, six companies (Air Products, Amoco, Dow, Ethyl, Mobil, and Tennessee Eastman) have sponsored modules.

The process simulations are written for Sun workstations running under UNIX and X Windows. The simulations are designed to be "user-friendly," employing a graphical user interface, pull-down menus, and extensive on-line help. A typical simulation consists of 10,000 lines of C and FORTRAN code, and closely models the behavior of an existing chemical plant.

These simulation modules have been used at Purdue and other universities for several years, and have proven to be an attractive alternative to traditional laboratory experiments. Using a simulation, students can investigate processes that would be not be feasible to operate in the university lab. Furthermore, the simulation programs are flexible, and can be used in courses other than the senior lab.

The Purdue modules provide a sense of realism that is unusual in the undergraduate laboratory. The students are given their assignment letters on official company letterhead. The assignments include an imaginary research budget from which the students must pay their experimental expenses. Nearly any action that the students take has a cost that must be paid from the budget. Additional "labor costs" are charged for overtime and weekend runs. (The professor even charges a "consulting fee" to answer students' questions.) This forces the students to plan carefully and to exercise good engineering judgement.

INTERACTIVE COMPUTER MODULES FOR UNDERGRADUATE CHEMICAL ENGINEERING INSTRUCTION

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The goal of the computer modules component of the project "A Focus on Developing Innovative Engineers", funded by the National Science Foundation, is to develop a complete set of interactive computer modules for courses in the undergraduate Chemical Engineering curriculum, where each computer module reinforces one of the key course concepts. Modules are then to be distributed free to all educational institutions. Modules for the Introduction to Chemical Engineering course have been tested and distributed, and modules are currently being tested in the Fluids/Transport, Separations, and Chemical Reactor Design courses.

The computer modules generally consist of a brief review of the material, followed by an interactive problem solving session. The optional review benefits a student who may not have understood the material by providing an additional, self-paced, presentation of the key concept. Some of the modules expose the student to new technologies (e.g. drug patches, chemical vapor deposition) and allow the student to learn by induction using a computer simulation of the processes involved. This provides a different experience than the typical classroom or homework experience. In addition, many of the problems to be solved are presented as part of an overall scenario, to capture the student's interest. This portion of the module also includes hints and reference screens to guide the student through the problem. Other modules provide for interactive testing of the subject matter, enhancing the learning experience for the student.

The development of modules has advanced to such an extent that module developed during the summer 1991 have been successfully used in the fall and spring semesters at the University of Michigan, with few adjustments suggested, either in the technical content or in the organization of the modules. Response to the modules from other universities has also been positive, with nearly 40 requests for even the testing versions of some of the modules at a recent national meeting.

PROGRESS IN COMPUTATIONAL ELECTROMAGNETIC MODELING FOR EM COURSEWARE: A PERSONAL PERSPECTIVE AT PENN STATE

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Recent advances in computational electromagnetic modeling makes it possible to provide students with interactive, color visualization of complex three dimensional phenomena on personal workstations in real time at reasonable cost.

The advances are: 1) the computational engines available, where we have found the finite difference time domain (FDTD) techniques to be most advantageous; 2) the availability of powerful workstations with extensive color graphics support, operating in the multi-megaflop regime; and 3) an emerging environment of courseware development support from a host of groups and agencies, including at Penn State, CAEME, and ECSEL, which permits development of student friendly interfaces or shells.

In our work the interface provides multiple problem types with a hierarchical level of problem sophistication ranging from demonstrations-to tutorials-on up to independent student design efforts. The student selects the problem type (a waveguide for example), the level of difficulty or interactivity suitable to his or her experience, inputs the required variables then watches as the system responds in time to the selected stimulus in the form of real time graphical display of the fields and interaction object.

The level of capability in computational modeling for EM courseware has evolved rapidly over just a few years, proceeding from one dimensional modeling then two dimensional, and now three. The need for color graphical display of the modeling results was apparent even in the early stages of development and has grown rapidly along with computational speed. At present there is still more to be obtained from increases in speed and graphical sophistication, however the greatest challenge is to lower costs making this approach to teaching more attractive.

INTEGRAL EQUATIONS IN ELECTROMAGNETICS FOR UNDERGRADUATES

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Undergraduate courses in electrical engineering dwell on differential equation methods, yet much of the practicable analysis of today in electromagnetics is based on integral equation techniques. To be prepared for demands on engineers of the future, a student should be exposed to integral equations and to simple methods for solving them, at least to the extent that an appreciation of what an integral equation is and how it differs from a differential equation can be acquired. If for no other reason, one can justify a brief study of integral equations on the basis that a young engineer should have some understanding of the principles that underlie the many computer codes that he/she will be expected to utilize in everyday engineering practice.

Instructional materials and attendant computer software have been developed to serve as aids to students who wish to learn methods for formulating and solving simple integral equations applicable to problems in electromagnetics. The materials, which are highly tutorial and suitable for self-study, comprise a general discussion of integral equations, step-by-step derivations of integral equations, and development of numerical methods for solving these equations. They include numerous examples illustrating the formulations and solution techniques, all supported by discussions of applications of these methods to sample problems of practical interest and by computer codes that enable a student to observe an implementation of the numerical solution method. The codes provide the opportunity for the student to view the solution and to test the sensitivity of the solution to changes in problem parameters. Exercises (problems) are provided which will give the student the opportunity to test his/her mastery of the material and to extend the material to current applications. A student may either write all code needed for solving the exercises or may take advantage of all or parts of blocks of code provided in the form of subroutines.

The notes describe derivations of integral equations and developments of numerical methods for solving many types of problems including: charged parallel conducting cylinders, isolated and coupled microstrip and stripline structures, charged thin-wire conductors, wire scatters and antennas (including simple arrays), and scattering of TM waves by conducting cylinders. All these examples are supported by computer codes.

Selected portions of the instructional aids and supporting computer codes will be described in the presentation and sample examples will be illustrated.

Wednesday PM AP-S, URSI-B, NEM Session WP06

Room: Columbus K/L *Time*: 1320-1700

Modern RCS Computation

Organizer: S. W. Lee, University of Illinois, Urbana-Champaign

Chairs: S. W. Lee, University of Illinois, Urbana-Champaign; Alex Woo, NASA Ames Research Center

1320 **MODERN RCS COMPUTATIONS - a PRACTICAL APPROACH**
Thomas A. Blalock*, U. S. Army Missile and Space Intelligence Center

1340 **RCS COMPUTATION at the SYRACUSE RESEARCH CORPORATION**
Chung-Chi Cha*, Syracuse Research Corporation

1400 **ELECTROMAGNETICS ANALYSIS CODES**
Dennis M. Elking*, Scott D. Alspach, Dwayne D. Car, Kirk E. Castle, Janice L. Karty, James H. Knehans, McDonnell Douglas Corp.; Ronald A. Pearlman, James M. Roedder, McDonnell Douglas Corporation

1420 **ELECTROMAGNETIC CODE CONSORTIUM**
James H. Kirkland*, US Army Missile & Space Intelligence Ctr

1440 **EFFICIENT SIGNATURE ESTIMATIONS in an ADVANCED GRAPHICS ENVIRONMENT**
Richard A. Shepherd, T. Olson, Charles S. Liang*, General Dynamics

1500 **Break**

1520 **RCS with TSAR FDTD CODE**
Scott L. Ray, S. T. Pennock*, Lawrence Livermore National Laboratory

1540 **RADAR CROSS SECTION COMPUTATIONAL TECHNIQUES**
Hung B. Tran*, Rockwell International

1600 **BENCHMARKING of RCS CODES**
Helen T. G. Wang*, Michael L. Sanders, Naval Air Warfare Center; Alex Woo, Michael Shuh, NASA Ames Research Center

1620 **RADAR CROSS SECTION COMPUTATION and VISUALIZATION by SHOOTING-AND-BOUNCING RAY (SBR) TECHNIQUE**
C. Long Yu*, Pacific Missile Test Center; S. W. Lee, University of Illinois, Urbana-Champaign

1640 **DISCUSSION**

MODERN RCS COMPUTATIONS - A PRACTICAL APPROACH

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ABSTRACT

Today, Radar Cross Section (RCS) calculations are being used for a variety of applications. Among these are design of low observable vehicles, missile fuzing studies, intelligence signature estimates, and determining material characteristics. Today's demand for RCS computations is increasing due to the high costs and limited budgets for RCS range measurements. RCS predictions require a variety of tools to be at the disposal of the analyst. Some of these tools exist and some are being developed.

The most important requirement of an RCS analyst is an understanding of the electromagnetic scattering mechanisms of the object to be modeled. This understanding is vital if one is to build good RCS models. In today's world of low observable targets, the RCS analyst can no longer use simple primitives (cones, spheres, ellipsoids, facets, etc.) to describe the surface curvature. A computer-aided-design (CAD) software package is required along with the ability to output geometry in a standard, widely recognized format. To act upon this geometry, a variety of RCS codes employing different methodologies are needed to cover the frequency range of interest. For so called "high frequency" cases where the wavelength is smaller than the object's smallest dimension, a physical optics, geometrical optics, uniform theory of diffraction code is needed. For "low frequency" cases where the wavelength is of the same order as the object's smallest dimension, a 2-d or 3-d method of moments code, a k-space code, or other low frequency code is required. Different codes are needed depending on far-field or near-field applications. Special codes are needed to deal with inlets, cracks, gaps, edges, wedges, and materials. Finally, after RCS has been calculated, a robust set of post-processing codes are required so that meaningful conclusions can be reached.

This paper addresses these requirements and describes a modern practical approach to the prediction of RCS.

RCS COMPUTATION AT THE SYRACUSE RESEARCH CORPORATION

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RCS Computation has been a main area of research work at the Syracuse Research Corporation (SRC) for a number of years. Sponsorships of projects in a variety of application areas over the years have enabled continuous research work in the field of electromagnetic scattering and the accompanying simulation software development. This paper will summarize SRC's work to date in this area.

Of quite some significance in SRC's history of RCS computation work was its pursuit in the late 1970's of an "active library" concept for the purpose of target identification. A critical element in this approach is a theoretical RCS prediction model which can accept an appropriate geometrical description of a target and relevant radar parameters, and accurately and quickly predict the target signatures. This motivation and other related projects resulted in, by the early 1980's, an RCS prediction software named SRCRCS, and an accompanying CAD modeling package named SCAMP. The theoretical prediction in SRCRCS is based on the theories of physical optics (PO) and the physical theory of diffraction (PTD), and the geometrical modeling in SCAMP is performed by using a combination of flat facets and a special class of canonical shapes.

The simulation software found a variety of applications. Besides assessment of target cross sections, and identification experiments, it also served as a very useful tool in many other problems. For example, it provided realistic data for use in the development of new signal processing algorithms. In the development of a training simulator of a ship identification system, it also provided realistic signatures in place of measurement data. To suit the variety of radar applications encountered, the computed RCS is post-processed and displayed in a variety of forms. This includes the CW angular display, wideband range profile, range-time or Doppler-time intensity plots, and two-dimensional image display.

Throughout the 1980's and the early 1990's, a number of capabilities were also added to the simulation system:

- Bistatic signatures.
- Absorber coated targets.
- 3-Dimensional method of moments solutions for metallic and dielectric materials
- Curved surface patch modeling.
- Multiple bounce.

ELECTROMAGNETICS ANALYSIS CODES

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Introduction: In recent years a requirement has emerged in the aerospace industry to analyze and design air vehicles with significant emphasis on reducing radar cross section (RCS). Typically both low frequency codes, such as method of moments (MOM), and high frequency codes, which use the physical theory of diffraction (PTD), are required to cover the design space. RCS computations are only made on the exact computer aided design and drafting (CADD) geometries, embodying vehicle design at various stages of development and used by automated machinery to mill components to precision tolerance. Connections exist to multiple geometry systems as well as the Initial Graphics Exchange Specification (IGES) standard.

RCS Codes: CADDSCAT has extensive capability to analyze these geometries at high frequencies, including the recently developed bistatic and near field options. MULTIRAY addresses high frequency multiple bounce combining ray tracing with PTD. CAVERN analyzes cavities such as inlets and ducts, combining ray tracing with modal solutions using a reaction integral. PLATE3D is a specialized MOM code for analyzing material treatments on rectangular plates. CLOAK is a recent innovation at MCAIR that provides generalized 3D MOM analysis directly from CADD patches, with an impedance boundary condition (IBC) option. Unique basis functions achieve an accuracy with only 4 unknowns per wavelength for which other codes, such as TSP, require as many as 15 to 20 unknowns per wavelength. All of these codes are linked to their geometry interface with IGES standard as a minimum.

The Electromagnetic Code Consortium
by James H. Kirkland

Abstract

In 1987, an initiative was made to consolidate radar cross section (RCS) code development sponsored by the Tri-Services, and NASA. An RCS Code Consortium was formed, consisting of a government steering group, and members from the industry/academic community. Since the formation of the Consortium, significant progress has been made to advance code development work sponsored by the U.S. government. This paper is intended to make the RCS community aware of the Electromagnetic Code Consortium, so that potential contributors to code development can become involved with the Consortium.

The objective of the Electromagnetic Code Consortium is to significantly advance the state-of-the-art in basic EM scattering research and to produce the computer codes necessary for prediction of military platform signatures. This shall be accomplished by determining the current state-of-the-art, and avenues for further advancement of electromagnetic radiation and scattering prediction codes. After developing the technology roadmap, the roadmap will be implemented through the development of highly efficient, modular computer codes, which form the basis for advanced RF, IR, and EO scattering and radiation analytical techniques. To assure compatibility, these modular codes shall share a common geometry package, allowing any or all of the individual modules to be linked and shared as required. A support contractor will be available to maintain a codes/documentation repository, to provide training, to insure distribution of software and documentation to consortium participants, and to provide assistance to operation maintenance and upgrades of codes in support of the Electromagnetic Code Consortium.

EFFICIENT SIGNATURE ESTIMATIONS IN AN ADVANCED GRAPHICS ENVIRONMENT

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AN ADVANCED TECHNIQUE HAS BEEN DEVELOPED FOR THE COMPUTATION OF PHYSICAL OPTICS BACKSCATTERING FROM LARGE, COMPLEX TARGETS OVER MULTIPLE FREQUENCY BANDS WITH UNPRECEDENTED SPEED. IT TAKES FULL ADVANTAGE OF THE POWER OF THE PRESENT (AND FUTURE) HIGH PERFORMANCE GRAPHICS ENGINES FOR SURFACE RENDERING AND SHADOWING. THIS METHOD HAS BEEN IMPLEMENTED WITH A FIRST-GENERATION CODE LABELLED VISAGE (VISUAL INVESTIGATION OF SCATTERING IN AN ADVANCED GRAPHICS ENVIRONMENT) ON THE SILICON GRAPHICS IRIS 4D SERIES WORKSTATIONS. THE COMPUTATION THROUGHPUT HAS SHOWN TO BE ESSENTIALLY INDEPENDENT OF THE TARGET COMPLEXITY AND THE DESIRED NUMBER OF FREQUENCIES. IN ADDITION, GEOMETRICAL SHADOWING OF TARGET COMPONENTS IS AUTOMATICALLY HANDLED.

THE TREMENDOUS AMOUNT OF DATA VISAGE IS CAPABLE OF GENERATING CAN BE EASILY INTERPRETED THROUGH THE USE OF MULTI-DIMENSIONAL COLOR GRAPHICS. THE VISAGE CODE INCLUDES VISUAL COMPUTATION WITH INTERACTIVE DISPLAYS. IN ADDITION, THE DATA FORMAT IS PERFECTLY SUITED FOR USE WITH MANY SOPHISTICATED POST-PROCESSING SCHEMES SUCH AS ISAR (INVERSE SYNTHETIC APERTURE RADAR) IMAGING FOR SCATTERING CENTER DIAGNOSTICS.

TARGET MODELS ARE GENERATED WITH THE GENERAL DYNAMICS ACAD (ADVANCED COMPUTER AIDED DESIGN) PROGRAM WHICH HAS BEEN DESIGNATED AS THE STANDARD GEOMETRY GENERATION CODE BY THE JOINT SERVICES ELECTROMAGNETICS CODE CONSORTIUM (EMCC). THE SYSTEM SUPPORTS DESIGN TECHNIQUES THAT INTEGRATES WIREFRAME, SURFACE, AND SOLID MODELING COMMANDS WITH OVER 900 OPTIONS. THE THREE MODELING TECHNIQUES ARE INTEGRATED THROUGH USE OF GEOMETRIC ASSOCIATIVITY TO ENABLE RAPID MODIFICATIONS IN A TYPICAL DESIGN ENVIRONMENT. ACAD PROVIDES MANY UNIQUE INTERFACE OPTIONS TO SUPPORT THE VARYING REQUIREMENTS OF SIGNATURE PREDICTION, AERODYNAMIC ANALYSIS, STRUCTURAL ANALYSIS, AND COMPUTATIONAL FLUID DYNAMICS.

RADAR CROSS SECTION COMPUTATIONAL TECHNIQUES

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We shall focus our discussion on 3 representative approaches for 3 classes of techniques used to perform radar signature calculations: (1) Asymptotic techniques: Physical Theory of Diffraction (PTD) approach. If the wavelength $\lambda = \frac{2\pi}{k}$ of a radar beam is small in comparison with the characteristic size of a scatterer, Maxwell's Eqs. can be solved approximately. Such a solution simulates accurately the specular and edge diffraction contributions to the scattered field for perfectly conducting and coated objects (E.Bleszynski, M.Bleszynski, H.B.Tran, *Physical theory of diffraction for scattering of electromagnetic waves of an arbitrary incidence angle from an impedance wedge*, Rockwell Int. report 1988). Radar signatures of 3-dim configurations are obtained within seconds on 20MIPS workstations. However, calculated radar signatures are insensitive to details of scattering structures of the order of λ or smaller, surface wave diffraction and multiple scattering effects are not included and electromagnetically penetrable regions can be modeled only approximately by the first (impedance) or higher order boundary conditions. (2) Techniques of solving Maxwell's Eqs. in the differential form: Finite-Volume Time-Domain (FVTD) approach. (3) Techniques of solving Maxwell's Eqs. in the integral form: Adaptive Integral Method (AIM) approach. The last two approaches provide exact numerical solutions to Maxwell's Eqs. They are expected to capture all relevant details of the scattering structure in a single computational framework. They both utilize algorithms in which memory and execution time scale linearly with the number of computational elements and are very well suited for massively parallel computational environment. In the FVTD (V.Shankar, W.Hall, A.Mohammadian, *A CFD-based finite volume procedure for computational electromagnetics - interdisciplinary application of CFD methods*, AIAA CFD Conference, Buffalo, New York 1989) approach Maxwell's Eqs. are written in the equivalent conservation-law form in the curvilinear body-fitted coordinates. The Lax-Wendroff integration scheme and the Riemann theory of characteristics are used to evaluate solution vectors in each computational cell. Curvilinear coordinates allow to divide the entire configuration into zones of different electromagnetic properties and to set up curvilinear grids of optimal density determined by local material properties in every zone.They assure high accuracy in implementing boundary conditions on zonal interfaces. The AIM (M.Bleszynski, T.Jaroszewicz, *An Adaptive Integral Equation Solver for Large Scale Electromagnetic Computations*, National Radio Science Meeting, Boulder, Co 1992) method is designed for solving Maxwell's Eqs. in the integral representation. The major advantage of an integral method is that the outer boundary conditions are inherently built into the formulation. Hence solving Maxwell's Eqs. outside the scattering body which often consumes dominant portions of CPU time and memory in partial differential equation solvers is not required. Numerical solutions for the currents induced on a target are sought on a multilevel nonuniform rectangular grid by solving the corresponding system of linear equations; the discrete fast Fourier transforms are applied to carry out fast and memory reduced matrix operations.

We shall present some applications of the discussed above approaches.

BENCHMARKING OF RCS CODES

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ABSTRACT

As the control and prediction of the electromagnetic (EM) signatures of air vehicles become more and more important, the electromagnetic scattering codes are facing more and more difficult problems. Unlike the conventional targets which consist of cylinders, frustums and plates, the targets with low radar cross-section have either stealthy smooth surfaces or radar absorbant material (RAM) coatings. Also the interest of observation angle is more towards grazing instead of broadside. Thus the secondary phenomena like surface waves, edges, and surface discontinuities are dominate. The accuracy of the prediction codes at low levels are far more important than before and a good set of measurement data is needed to validate the prediction codes.

Several sets of targets were built and measured for validating the computational electromagnetic codes as they apply to different problems. The problems include 3D metallic, and coated targets, 3D bulk dielectric material, 2D metallic targets, cavities, and plates close to grazing for edge waves.

It is our intent to publish all the data we obtained and distribute to the EM community for diagnostic and validation purpose. We hope this stimulates more research and improvement of the computational electromagnetic codes.

RADAR CROSS SECTION COMPUTATION AND VISUALIZATION BY SHOOTING-AND-BOUNCING RAY (SBR) TECHNIQUE

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In the course of analyzing the radar cross section (RCS) of a complex target, the accurate prediction and determination of the scattering mechanisms as well as the identification of the electromagnetic scattering centers on a complex platform often pose a great challenge to the RCS analysts/engineers. Especially when the backscattering returns are due to the multiple reflections among target airframe, stores and engine inlets, it is almost impossible to pin-point the exact causes and locations of the scattering mechanisms. Although the high-resolution radar imaging technique has widely been used in many test facilities to perform RCS diagnostic studies, the effectiveness of this method is still limited in accurately determining and explaining the causes of the scattering phenomena.

An effort is currently being conducted to develop an analysis model with sophisticated graphic capability for analyzing and visualizing the electromagnetic scattering from a complex radar target. This analytical model employed a hybrid technique of the shooting and bouncing ray (SBR) method and the Physical Theory of Diffraction (PTD). The proposed SBR/PTD method employes rigorous use of theoretical foundations of Geometric-Optics (GO) and PTD by including the following four steps in the electromagnetic calculations: (1). The divergence factor of a ray pencil, (2). A rigorous wavefront integration technique at the exit point, (3). The first order edge diffraction, and (4). Radar absorbing material characteristics.

Coupled with computer-aided design (CAD) graphics, the model provides a new capability for visualizing, analyzing, and interpreting the complex radar scattering phenomena via dynamic ray-picture displays on a computer graphic terminal. With its sophisticated capability to rapidly conduct visual diagnostic studies of radar scattering sources and multiple reflections form a complex target, the SBR model provides RCS engineers an efficient and cost-effective way of performing many practical RCS analysis, design and reduction applications that are not feasible in the past. In addition, this method can be used to complement the experimental measurements in maintaining the quality assurance of the test data measured.

Thursday AM URSI-E, NEM Session RA09

Room: Columbus E/F *Time*: 0820-1200

EM Topology

Organizer: P. Degauque, Universite de Lille
Chairs: Carl E. Baum, Phillips Laboratory; P. Degauque, Universite de Lille

0820 **INTEREST of a TOPOLOGICAL APPROACH for the STUDY of ELECTROMAGNETIC COUPLING**
J. P. Parmantier*, Dassault Aviation

0840 **TOPOLOGY BASED ELECTROMAGNETIC INTERACTIONS MODELLING**
Joe LoVetri*, University of Western Ontario; George I. Costache, University of Ottawa

0900 **AN APPLICATION of E.M. TOPOLOGY to a COMPLEX SYSTEM**
V. Gobin*, F. Issac, J. P. Aparicio, ONERA; I. Junqua, A. Madore, Centre d'Etudes de Gramat; J. P. Parmantier, Dassault Aviation

0920 **TREATMENT of NON-UNIFORM COUPLED LINES in a QUANTITATIVE TOPOLOGICAL APPROACH**
P. Besnier, P. Degauque*, B. Demoulin, Univ. des Sciences et Tech. de Lille

0940 **EQUALIZATION of LOSSY MULTICONDUCTOR TRANSMISSION LINES**
Jurgen Nitsch*, NBC Defense and Research Institute; Carl E. Baum, Phillips Laboratory; Richard Sturm, NBC Defense and Research Institute

1000 **Break**

1020 **NORM DETECTORS for MULTIPLE SIGNALS**
Carl E. Baum*, Phillips Laboratory

1040 **APPLICATION of NUMERICAL CODES to the STUDY of ELECTROMAGNETIC COUPLING**
X. Ferrieres*, V. Gobin, ONERA

1100 **ON the CONCEPTUAL FOUNDATION for DETERMINING the PROBABILITY of SURVIVAL for ELECTRONIC and COMMUNICATIONS SYSTEMS EXPOSED to EMP**
Ira Kohlberg*, Shawn C. Whetstone, Institute for Defense Analyses

1120 **CLASSIFICATION of ELECTROMAGNETIC ENVIRONMENTS for EMP HARDENING STANDARDS**
Torbjorn Karlsson*, EMTECH

1140 **PANEL DISCUSSION on FUTURE of EM TOPOLOGY**

INTEREST OF A TOPOLOGICAL APPROACH FOR THE STUDY OF ELECTROMAGNETIC COUPLING.

J.P. PARMANTIER,
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Electromagnetic Topology is an original and powerful formalism developed in the seventies by C.E Baum et al. to solve internal electromagnetic problems on complex systems. The spirit of the method is to make the approximation that independent volumes can be defined in the structure to avoid a complete resolution on the whole geometry. The art of Topology then is, to bring together the elementary problems associated with each volume in order to obtain the response of the global system. To our knowledge, no application of this method had been published, till 1988, when ONERA, Dassault Aviation and Lille University decided to answer the question: can it be applied in aeronautics ? In 1992, after all the work we have done on the subject, we think that the application to industrial problems is feasible indeed.

Firstly, we present our personal view on the original formalism. Next, the benefits of the method will be shown. Particularly, a descriptive Topology and a quantitative Topology will be distinguished. The first one can be very useful to organize E.M coupling problems; employed as early as the design stage of an industrial product, the method allows for an optimization of the protections and the future maintenance, and makes all the certification studies easier.

Directly following the topological analysis, the quantitative Topology deals with the prediction of interference levels. The way to generalize a multiconductor line network formalism, specially well suited for lightning and EMP, will be dicussed.

Finally, examples dealing with the way to characterize a penetration path in a tological sense and the application of the method to a complete system will put forward the importance of the method.

TOPOLOGY BASED ELECTROMAGNETIC INTERACTIONS MODELLING

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The electromagnetically relevant attributes of an electrical system can be isolated by decomposing the system into an *electromagnetic shielding topology* and its dual graph or *interaction sequence diagram*. The interaction sequence diagram can be simply derived from a given electromagnetic topology. The electromagnetic topology consists of a description of the electromagnetically distinct volumes and their associated surfaces. The volumes define the *electromagnetic components* involved in the interaction. The interaction sequence diagram keeps track of the *interaction paths* throughout the system. The nodes in the topology are characterized as being either ***field nodes, circuit nodes*** or ***interaction path nodes*** (J. LoVetri & G.I. Costache, *IEEE Trans. on EMC*, vol. 33, no. 3, pp 241-251, Aug. 1991). Nodes are then given electromagnetic attributes which define the node's susceptibility and disturbance level (field and circuit nodes) or shielding effectiveness (interaction path nodes). These attributes are necessarily approximations to the processes which manifest the actual physical interaction problem. The form of these approximations as well as the operators which model the interaction between nodes will be discussed. Sources of error include: coarseness of the topological decomposition; type and approximation of attribute values; propagation of disturbances through the topology; and comparison of disturbance impinging at a node to the node's susceptibility level. A new formulation based on approximating the relevant attributes in the topology with trapezoidal fuzzy variables is also discussed. The implementation of these techniques into computer software simplifies the analysis and hardening process since, typically, a real system's topology consists of many nodes with many interaction paths. Future directions in this area of research will also be discussed.

AN APPLICATION OF E.M. TOPOLOGY TO A COMPLEX SYSTEM

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Since 1988, we tried to apply Electromagnetic Topology concepts to complex structures to give an evidence of its great help in industrial programs. All the work we performed led us to elaborate a numerical code named CRIPTE, originally inspired by the multiconductor transmission line network formalism, but generalized to E.M. Topology.

This tool and the concepts of the method have been validated on a common experiment performed in a collaboration between ONERA and CEG (Centre d'Etudes de Gramat). The structure under test was a caisson composed of five elementary subvolumes organized in the shape of a cross. Each volume was equiped with multiconductor lines running through the structure. Some paths could be considered as canonical, but others were more complex: indeed some cables were located near structural elements and geometical "defects". In particular an electronic equipment,connected to the internal wiring by means of shielded coaxial cables,has been simulated by a black box.

The external excitation was made by means of three apertures located in three of the elementary subvolumes. Several experimental methods of injection have been studied (direct injection on wiring; use of local strip-lines). A special one dealt with a coaxial cable unshielded at the aperture level. An experiment with the entire caisson under an EMP simulator (SSR) has also been performed.

The method to characterize the elementary subvolumes of the caisson in a topological way will be presented. We shall also show global frequency domain simulations dealing with the coupling on the whole structure. The use of transfer functions to predict the time response of the system will also be discussed.

TREATMENT OF NON-UNIFORM COUPLED LINES IN A QUANTITATIVE TOPOLOGICAL APPROACH

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In most cases, the calculation of electromagnetic disturbances induced on cable networks must take the non-uniformity of these cables into account. If we consider the simple example of cables parallel to a ground plane, a local non-uniformity occurs when either the height of the cable bundle above the plane varies continuously from one point to another one, or when this bundle divides into two or many parts. Applying the coupled transmission lines theory leads to second order differential equations with coefficients depending on the position of the cables.

For some configurations such as crossing wires or a wire whose height above the ground plane varies linearly... analytical solutions have been found and which are very useful for physical interpretation. However, these approaches cannot easily implemented into a numerical code based on the generalized transmission line equation used in the topological model and usually called B.L.T. equation (C. Baum, Transfer of norms through black boxes, Interaction Notes, Note 462, 1987). A solution consists in approximating a non-uniform structure by a series of small uniform structures separated by small discontinuities. The scattering parameters of this set of discontinuities are calculated and introduced into the B.L.T. equation formalism. S topological parameters have to be determined. Usually they are calculated from S_{50} parameters which are scattering parameters measured with respect to 50 Ohm. In case of ideal junction the matrix $\{ [U] - [S_{50}] \}$ where [U] is the unity matrix is singular. Then, the transformation of $[S_{50}]$ into [S] is impossible. But one shows that topological S calculation is performed directly by defining some matrices which are combinations of rows and columns of general characteristic impedance matrix, depending on the way conductors are connected. The theoretical approach will be presented together with a comparison between theoretical and experimental results on few examples (crossing cables, non parallel cables...).

EQUALIZATION OF LOSSY MULTICONDUCTOR TRANSMISSION LINES

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Abstract

The exact analytical treatment of lossy multiconductor transmission lines (MTLs) is a very difficult task. The pairwise commutation of all relevant physical matrices occurring in the MTL equations can be used to decouple these equations by virtue of a diagonalization procedure. In this case an analytical solution is essentially simplified.

The requirement of commutativity on the other hand, of course, restricts the admitted classes of MTL configurations. In former publications (J. Nitsch, C. Baum, R. Sturm) we investigated circulant matrices and complex matrices which are the product of a real symmetric matrix times a complex valued function.

A special application of our general results to lossy MTLs over a lossy ground leads to an interesting aspect: It becomes possible to adjust the losses of the lines with those of the ground plane (reference conductor) such that the eigenvalues of the characteristic impedance matrix become those of a distortionless conductor system. Furthermore, for a chosen two - and three - multiconductor configuration we can match ground- and wire-losses in a way that the resulting eigenfunctions of the corresponding propagation matrix turn out to be equal to each other. This implies that all propagation modes of the conductor system have the same attenuation and the same velocity, in some cases even no dispersion occurring. The above procedure might become of some importance when one tries to transmit signals without distortion, in close analogy to the "equalization" of lossy telephone lines.

NORM DETECTORS FOR MULTIPLE SIGNALS

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One is often confronted with the problem of measuring a large number of electrical signals in some object (system) under test. These may be in either frequency or time domain. What is it about these signals that one can or should measure? For example, one might attempt to measure many thousands of time-domain signals, perhaps for each of several different orientations of the system in say some set of EMP simulators. This represents an enormous amount of time-sampled (or frequency-sampled) data to collect, store, and process before one attempts to draw conclusions from the test. Is there some way that one can compress or reduce the amount of data to be taken, stored, and processed while still being able to draw valid conclusions concerning the system performance? This paper addresses this question in terms of appropriate bounds on the signals in terms of norms. Norms provide a powerful concept for characterizing a set of waveforms as single, real, non-negative number. This can be used to give a bound on every waveform in the set. If one has a specification that all signals at a set of pins (in a system in some test electromagnetic environment) be less than some amount stated in such a norm sense, then a norm detector has the potential of simplifying the test.

The design of such a norm detector poses various technical problems. One of these concerns the perturbation of the voltages or currents to be measured. The actual sensor responding to each of the voltages (e.g. a parallel (to local ground reference) small admittance resistor) or currents (e.g. some small-insertion-impedance inductive coupling device) must give a negligible perturbation. For this purpose one needs to bound the appropriate eigenvalues of the source and input matrices (combined). Even the geometrical size of the devices in contact with or proximity to the pins or associated wires can be of concern because of the close packing of a large number of wires in a cable bundle or connector.

APPLICATION OF NUMERICAL CODES TO THE STUDY OF ELECTROMAGNETIC COUPLING

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In spite of the increasing performances of modern computers, it seems that the study of the electromagnetic coupling on a complex structure (such as an aircraft) is out of the capability of an only simulation taking into account all the interactions. The use of the Electromagnetic Topology formalism supposes that independant volumes can be defined in the structure and thus avoid the complete resolution of the whole problem. The numerical code CRIPTE based on a multiconductor lines network formalism can be used to connect elementary volume togather.

The objectif of this paper is to illustrate how electromagnetic numerical codes can help to fill a topological network with proper datas. Such a network can be descrided by means of 3 types of datas: **junctions** are represented by scatterring parameters, **multiconductor lines** are simulated by inductance and capacitance matrices (or speed and characteristic impedance), and the **sources** are applied by means of current and voltage generators on the lines. To complete experimental measurement of these parameters, various numerical codes can be used and some exemple are discussed:

- The first code is based on a quasistatic magnetic calculation of the current distribution on parrallel wires modelled by their mutual inductances. It can calculate some of the muticonductor lines parameter taking into account the return path of the currents.
- The second code is based on the Method of Moments solution of integral equations in the frequency domain. Exemples of the calculation of Thevenin equivalent generators are given.
- The last code gives a finite difference solution of the Maxwell Equation in time domain. Short-circuit fields on an aperture can be considered as the source terms to introduce in a complete network.

Most of the numerical results are discussed and compared to experimental datas obtained on a complex structure both in time and frequency domains.

ON THE CONCEPTUAL FOUNDATIONS FOR DETERMINING THE PROBABILITY OF SURVIVAL FOR ELECTRONIC AND COMMUNICATIONS SYSTEMS EXPOSED TO EMP

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This paper examines the concept of Probability-of-Survival, P_s, and the associated issue of confidence for electronic and communications systems exposed to the High Altitude EMP (HEMP) threat. *P_s is defined as the probability that all Mission Critical Functions (MCF) of the system will survive and that the system will complete its mission.* The determination of P_s is therefore a Bernoulli process with two outcomes: success (survival) or failure. The confidence, C, is a measure of the certainty ($0 \leq C \leq 1$) with which we can determine P_s.

The uncertainty in the prediction of P_s arises from the stochastic nature of the threat waveform $\vec{E}$. This randomness is embodied in the uncertainty parameters $\tilde{\eta}$, associated with the HEMP source mechanisms, and $\tilde{\Omega}$, associated with geometric factors and polarization. $\vec{E}$ is thus a random function $\vec{E}(t, \tilde{\eta}, \tilde{\Omega})$ from the sample description space defined by $\tilde{\eta}$ and $\tilde{\Omega}$. If $f_\eta(\tilde{\eta})$ and $f_\Omega(\tilde{\Omega})$ are the probability density functions for $\tilde{\eta}$ and $\tilde{\Omega}$ respectively (i.e. their assumed frequency of occurrence), we have

$$P_s = \iint f_\eta(\tilde{\eta})\, f_\Omega(\tilde{\Omega})\, d\tilde{\eta}\, d\tilde{\Omega}\,, \qquad (1)$$

where the domain of integration extends over all values of $\tilde{\eta}$ and $\tilde{\Omega}$ for which all the MCF survive.

P_s is difficult to determine purely analytically. In *principle*, it can be determined by simulation provided *all* possible values of $\tilde{\eta}$ and $\tilde{\Omega}$ are used. This is defined as ideal simulation, and it is not practical. Instead, we can select a finite set: ($\tilde{\eta}=\eta_1, \eta_2, \eta_3, \ldots \eta_N$; $\tilde{\Omega}=\Omega_1, \Omega_2, \Omega_3, \ldots \Omega_L$), and examine the number of times, M, that all the MCF survive. The approximate P_s is $\hat{P}_s = (M/LN)$ which is the ratio of the number of success to the total number of tests, N_0=LN. Confidence, C, is a measure of the degree to which $\hat{P}_s$ approximates P_s. C depends on the number of tests, N_0, and the desired degree of approximation defined by a small parameter, ε. We evaluate and compare the calculation of C as a function of N_0 and ε using Chebyshev's Inequality, a Bayesian approach, and Non-Parametric Statistics.

Methods for determining P_s are explored. The methods are based on the use of transfer functions that connect the excitation at each POE to a particular piece of mission critical equipment. Using topological considerations developed by Baum we show that the EMP-created stress (voltage or current) can be expressed as

$$\chi_\mu^{(j)}(t, \tilde{\eta}, \tilde{\Omega}) = \sum_k \vec{\varphi}^{(k)}(\tilde{\Omega}) \cdot \int_0^t \vec{g}_\mu^{(j,k)}(t-\tau)\, E(\tilde{\eta},\tau)\, d\tau\,, \qquad (2)$$

where $\vec{g}_\mu^{(j,k)}$ is a vector function that depends on the interior coupling between the k^{th} POE and pin μ of mission critical equipment j, $\vec{\varphi}^{(k)}$ is a vector function that depends on the orientation variables and location of the k^{th} POE, and $E(\tilde{\eta},\tau)$ is a scalar field.

Methods for independently determining, $\vec{g}_\mu^{(j,k)}$ and $\vec{\varphi}^{(k)}$ using combinations of EMP test facilities are examined. The net effect is that the EMP-created stress can be expressed in terms of the random variables, $\tilde{\eta}$ and $\tilde{\Omega}$. Using appropriate failure criteria, methods are presented for calculating P_s using Equation (1).

CLASSIFICATION OF ELECTROMAGNETIC ENVIRONMENTS FOR EMP HARDENING STANDARDS.

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Two sets of Swedish defense standards have been drafted, one containing immunity test methods and requirements on equipment, and another specifying the EMP environment into four different classes along with test procedures for determining the actual EMP response. Testing according to the immunity standards can be used to verify that equipment will function in a specified EMP environment. Testing according to the environment standard will be used to find the actual EMP response of a system inside a given topological volume, and after that classify the environment into one out of four classes.

In immunity standards test levels are specified for the succeptibility testing of equipment. Those levels have to correspond to an EMP environment that is specified in the environment standard. By establishing four specified EMP environment classes many advantages are gained, for example:

- Instrumentation for immunity testing is limited to few specified test levels and less costly than a more general test instrumentation.

- Environment specification is limited to a few levels — in practice only two EMP hardened levels — thereby facilitating decision making.

The environment classes are chosen to correspond as much as possible to certain types of practical facilities. In the long run, this makes it possible to perform a preliminary class determination by experience, rather than testing.

Four EMP environment classes have been suggested:

Class #1 is the unattenuated EMP field and unattenuated EMP induced currents in long lines.

This class is expected on all unhardened sites.

Class #2 is almost the same as class #1, except for a low frequency attenuation of currents. The raison d'être of this class is the prospective possibility of including lightning in the same environment classes.

This class is expected on unhardened sites with low frequency "lightning grounding" of cable shields and surge arresters.

Class #3 is an environment that is attenuated at least one order of magnitude from that of the EMP field, up to 200 MHz. Currents are low pass filtered.

This class corresponds to environments within volumes inside concrete buildings, which have all cable penetrations gathered at one entry plate that is well connected to the rebar structure.

Class #4 is an environment in which the EMP contribution is negligible.

This class will be found in all EMP protected facilities with high quality hardening.

Expected field strengths for the different environment classes have been calculated, and test currents for corresponding immunity classes have been determined. Damped sinusoidal test pulses of the same kind as in MIL-STD-461, CS 11-12 can be used. Examples of amplitudes at different frequencies for a given safety margin will be given in this paper.

Thursday PM URSI-B E, NEM Session RP02

Room: Grand B *Time*: 1320-1700

High Power Microwaves

Organizer: D. Giri, PROTECH

Chairs: D. Giri, PROTECH; Albert W. Biggs, The University of Alabama at Huntsville

1320 **GENERAL CONSIDERATIONS in SPECIAL HPM**
Carl E. Baum*, Phillips Laboratory

1340 **TRENDS and BOUNDS in RF COUPLING to a WIRE INSIDE a SLOTTED CAVITY**
K. S. H. Lee*, F. C. Yang, Kaman Sciences Corporation

1400 **TIME-DOMAIN ELECTROMAGNETIC PENETRATION THROUGH ARBITRARILY SHAPED NARROW SLOTS IN CONDUCTING SCREENS**
Erik K. Reed*, KEMET Electronics Corp.; Chalmers M. Butler, Clemson University

1420 **CALCULATION of APERTURE COUPLING by MEANS of the ELECTRIC FIELD INTEGRAL EQUATION (EFIE)**
C. D. de Haan*, TNO Physics and Electronics Laboratory

1440 **CALCULATION of the BANDWIDTH BROADENING of HIGH-POWER MICROWAVE PULSES by AIR BREAKDOWN in a RECTANGULAR WAVEGUIDE**
D. J. Mayhall*, J. H. Yee, R. A. Alvarez, Lawrence Livermore National Lab

1500 **Break**

1520 **ANTENNA CONCEPTS for HIGH POWER MICROWAVE APPLICATIONS: SYNTHESIS, ANALYSIS and DESIGN ISSUES**
Y. Rahmat-Samii*, Dah-Weih Duan, University of California, Los Angeles; L. F. Libelo, Harry Diamond Laboratories; D. Giri, PROTECH

1540 **ANALYTICAL and EXPERIMENTAL STUDIES of a MAGNETICALLY INSULATED TRANSMISSION LINE OSCILLATOR**
Albert W. Biggs*, The University of Alabama at Huntsville

1600 **HIGH POWER NONRESONANT VIRTUAL CATHODE OSCILLATOR**
C. Leibovitz, A. Rosenberg, B. Mandelbaum, J. Shiloh*, RAFAEL

1620 **PHASE-LOCKING of STRONGLY COUPLED RELATIVISTIC MAGNETRONS**
H. Sze*, R. R. Smith, J. Benford, B. Harteneck, Physics International Company

1640 **ON the USE of the HILBERT TRANSFORM for PROCESSING MEASURED CW DATA**
Frederick M. Tesche*, Electromagnetics Consultant

GENERAL CONSIDERATIONS IN SPECIAL HPM

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In the evolution of EMP technology we have reached the point where people are considering how to produce similar effects by more conventional means and how to protect against such threats. This is the subject of special high-power microwaves (HPM). While, as a practical matter, we can consider the traditional type of EMP waveform as given, it is by no means an optimum waveform for interaction with electronic systems and producing EMP-like upsets and failures. This allows one to design a waveform which more efficiently interacts with the system via an appropriate transfer function resonance, i.e., an approximate sinusoid in the microwave region.

In designing such a special HPM device one must consider the overall problem from source to signal at the failure port of interest in the electronic system. This can be handled by considering each term in a product of transfer functions. For the source we need to characterize the power as a function of frequency which can be delivered into the lowest order mode $H_{1,0}$ of a standard rectangular waveguide (the useful power). This can be cast in the form of an effective voltage which in general is a decreasing function of frequency. This power is fed to a special reflector antenna which gives a transfer function to the far electric field which is an increasing function of frequency and is proportional to the aperture area of the reflector. For locations near the earth surface there is a breakdown field limitation in the MV/m range. Staying below this field will simplify the propagation (approximately no attenuation). At higher altitudes this attenuation consideration is more severe. Interaction with the system is a complex item, but a canonical response for unintentional interaction paths (back door) can be developed into low-frequency (differentiation), resonant-region, and high-frequency (integration) regimes. In this case the overall performance is optimized with a frequency chosen near the top of the resonance regime, or roughly a GHz. The pulse width should be on the order of a hundred cycles so that an appropriate system response can be rung up to get maximum internal response.

TRENDS AND BOUNDS IN RF COUPLING TO A WIRE INSIDE A SLOTTED CAVITY

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ABSTRACT

This paper considers how to bound the power picked up by a wire inside a cavity with a slot in its wall. The consideration is based on equivalent circuits and power conservation, and is general enough for applications to real-world systems. The calculations compare favorably with measurement data.

Recently some progress has been made on calculating the bounds of RF coupling to the interior of a system. The bounds are on the coupling cross section σ and the integral of it over all wavelengths, namely

$$\int_0^\infty \sigma d\lambda \leq \pi^2 V(P_{11} + M_{22}) \quad (1)$$

Eq.(1) is useful in two ways. It bounds the behavior of σ at low and high frequencies. It can also be utilized to obtain some upperbound energy that an incident electromagnetic wave can penetrate into the interior of a system, given the geometries and the distribution of its POEs. Warne and Chen have skillfully applied (1) to bound EMP coupling problems (EMC Vol. 32, No. 3. pp. 217-221, August 1990). Noticing that the left-hand side of (1) is proportional to the total absorbed energy for a step function incident plane wave, they have shown that

$$2\int_0^\infty \sigma\, S_{inc}\, df \leq \frac{1}{2}\mathbf{E}_o \cdot \mathbf{p} + \frac{1}{2}\mathbf{H}_o \cdot \mathbf{m} \quad (2)$$

The left-hand side is the energy absorption, and the right-hand side is the total energy stored in the induced electric and magnetic dipoles $\mathbf{p}$ and $\mathbf{m}$. Making use of (2), one can also write down the exact solution to the boundary-value problem of calculating the total energy (Wt) transmitted by a step-function plane wave, $\mathbf{E}_{inc} = \mathbf{E}_o\, u(t - x/c)$, through an aperture in an infinite, perfectly conducting ground plane. The solution is

$$W_t = \mu_o\, \mathbf{H}_o \cdot \boldsymbol{\alpha}_m \cdot \mathbf{H}_o - \varepsilon_o\, \mathbf{E}_o \cdot \boldsymbol{\alpha}_e \cdot \mathbf{E}_o \quad (3)$$

where $\boldsymbol{\alpha}_e$ and $\boldsymbol{\alpha}_m$ are the electric and magnetic polarizability tensors of the aperture.

TIME-DOMAIN ELECTROMAGNETIC PENETRATION THROUGH ARBITRARILY SHAPED NARROW SLOTS IN CONDUCTING SCREENS

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A time-domain integral equation is presented that governs the unknown electric field, or equivalent magnetic surface current, in an aperture of general shape in a planar conducting surface of infinite extent. The equation is specialized to the case that the aperture is a narrow slot of arbitrary contour. An efficient and stable "marching in time" numerical method is developed for solving the general slot equation. From knowledge of the slot magnetic current, the shadow-side electric field that penetrates the slotted screen is computed. The solutions for magnetic current and shadow-side field are compared via Fourier transformation with those obtained by solving the corresponding time-harmonic integral equation. Results are further validated by demonstrating close correlation between values of the calculated field on the shadow side of the conductor and data derived from laboratory measurements. For numerous slot lengths and shapes, time- and frequency-domain data illustrating the behavior of the slot field and penetrated field are presented and compared with measured results. The general features of the computed and measured magnetic currents and fields are explained and are related to practical questions that may arise in shielding applications.

The stability of the time-domain solution technique is investigated and found to be very high. This is demonstrated by observing the data decay "naturally" to a small fraction of a percent of peak values and then on to "0" after several thousand time steps, without evidence of the usual behavior associated with instability. The steps taken to achieve such stability are discussed.

The apparatus and methods employed to measure shadow-side electric field are described, including a brief outline of the calibration procedure.

The responses of a slot to an EMP-type pulse and to a Gaussian pulse are presented as examples.

CALCULATION OF APERTURE COUPLING BY MEANS OF THE ELECTRIC FIELD INTEGRAL EQUATION (EFIE)

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Energy associated with electromagnetic (EM) radiation can penetrate into a metallic structure such as an aircraft, missile or a system connected with cables. The unintentional coupling of RF energy through apertures (back door coupling), such as windows, wheel bays and imperfections of the walls can have disruptive or damaging effects on a variety of electrical or electronic systems inside the enclosure.

An electric field integral equation (EFIE) computer program based on the Method of Moments is used to calculate the EM coupling of apertures in perfectly conducting bodies. The EFIE program calculates the EM-scattering by arbitrarily shaped objects. The program computes the induced surface current distribution and the electric or magnetic fields surrounding the body. The EFIE formulation is applicable to both open and closed surfaces, and is often used for RCS prediction techniques.

In this presentation a cylinder is modelled as a surface patch model. Rectangular and circular apertures were placed in the front and back surface of the cylinder. The dimensions of the apertures can be extended to a few wavelengths of the incident field. The results for several body configurations will be presented.

CALCULATION OF THE BANDWIDTH BROADENING OF HIGH-POWER MICROWAVE PULSES BY AIR BREAKDOWN IN A RECTANGULAR WAVEGUIDE*

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Wideband, high-power microwave pulses are expected to have a number of important future applications. One convenient way to generate such pulses with fairly conventional, presently existing technology is to erode the tails of short (3–10 ns), high-amplitude (>0.5 MV/m) pulses in a low-pressure air cell. The pressure should be matched to the incident pulse characteristics so that sufficient air breakdown occurs to cause severe tail erosion. This erosion shortens the pulses and thereby broadens the bandwidths.

We have experimentally demonstrated that such tail erosion broadens the 3 dB bandwidths of 8 ns, 0.67–1.16 MV/m, 2.8608 GHz pulses in a WR-284 rectangular waveguide at the air pressure of 3.5 torr. Preionization from a ^{60}Co gamma source generated a localized background electron population, which ensured reproducible air breakdown from the incident pulses. The bandwidth was broadened from 0.147 GHz by 0.0097–0.039 GHz (0.34–1.4% relative to the incident carrier frequency). This broadening was simulated with a two-dimensional, electromagnetic, finite difference, electron fluid code, predicting broadening by 0.029–0.13 GHz (1.0–4.4%).

The code also predicts the bandwidth broadening of idealized incident pulses with an 0.5 ns linear rise and a 3.0 ns linear fall. These pulses enter a rectangular waveguide cell at 3.5 torr, containing a spatially Gaussian background electron distribution with an axial FWHM of 3 cm. The transverse FWHM in the waveguide "a" direction and the peak electron density are variable. The incident bandwidth is 0.342 GHz (12%). Calculations are performed for incident amplitudes of 1–18 MV/m, peak electron densities of 10–10^{11} cm^{-3}, and transverse FWHMs of 3 and 10^4 cm. The transmitted bandwidth varies from 0.352–3.214 GHz (12.3–112%), the transmitted center frequency varies from 2.87–4.72 GHz, and the transmitted amplitude varies from 1.10–12.7 MV/m at 54.6 cm from the cell input port. Because of the linearity of the empty wave-guide, the transmitted bandwidth will remain constant with propagation down the waveguide. The transmitted amplitude will vary with axial position as the spectral components rearrange themselves due to dispersion. For a peak density of 10^9 electrons/cm^3, the amplitude at 54.6 cm from the input varies from 0.617–2.06 MV/m; whereas, that at 69.8 cm varies from 0.581–2.05 MV/m. For several values of incident amplitude, the amplitude at 69.8 cm exceeds that at 54.6 cm.

Air breakdown at low pressure should afford a promising, convenient method for generation of wideband, high-power microwave pulses with presently existing technology. The electron fluid code should provide a unique capability for investigation and design.

ANTENNA CONCEPTS FOR HIGH POWER MICROWAVE APPLICATIONS: SYNTHESIS, ANALYSIS AND DESIGN ISSUES

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There has been considerable amount of research activities in the areas of the optimum transformation of high power electromagnetics fields to different distances. One of the key elements in the overall system realization is the proper utilization of an optimized radiating antenna. The main task of this radiating antenna is to be able to focus the electromagnetic energy toward particular directions and distances in the most efficient manner.

In this paper, applications of different antenna systems to produce directive High Power Microwave (HPM) radiations are first reviewed. The overall system architecture including reflector antenna configuration, source, waveguide, and feeds is detailed. The key design issues are summarized and novel synthesis/analysis techniques utilizing a newly developed diffraction optimization synthesis technique are discussed. Representative design concepts are presented for an optimized dual shaped reflector antenna system in order to maximize the antenna performance for a 7-element feed array considering the air breakdown issues. Representative results will also be shown for the transient behavior of the radiated field.

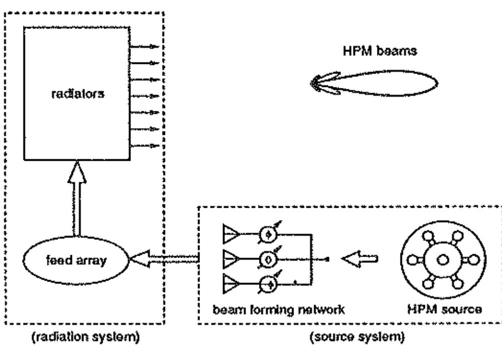

Figure 1: Basic functional units of an HPM antenna system.

ANALYTICAL AND EXPERIMENTAL STUDIES OF A MAGNETICALLY INSULATED TRANSMISSION LINE OSCILLATOR

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ABSTRACT

The magnetically insulated transmission line oscillator (MILO) is a coaxial transmission line (CTL) whose outer anode conductor is a set of periodically spaced corrugations, or cavities, aligned parallel to the axis of the center conductor, or cathode, axis. The slow wave structure are rectangular teeth with gap width B (1) = 0.7 cm, depth L (1) = 1.8 cm, period D (1) = 1.4 cm, cathode radius R (I) = 6.5 cm, and anode radius R(O) = 8.5 cm.

Anode corrugations or radial cavities allow the CTL to generate electromagnetic waves which propagate axially with phase velocities less than the velocity of light. These "slow waves" are like those in traveling wave tubes. The slow waves have phase velocities which increase to those of light as the serrations become shallower and wider, becoming smooth coaxial conductors when the antenna is reached.

High power microwave generation in MILO is achieved when operated as a magnetically insulated transmission line ([1] Raymond Lemke and Collins Clark, "Theory and simulation of high-power microwave generation in a MILO," J. Applied Physics, Vol. 62, pp. 3436-3440, 15 Oct. 1987). The applied voltage between electrodes is high enough to create field-emission-induced plasma at the cathode. Electron flow from cathode to anode is radial because of the high radial electrical field, but the magnetic field created by the power flow insulates the cathode by preventing electrons emitted by the cathode from reaching the anode ([2] Marco Di Capua, "Magnetic insulation," IEEE Trans. Plas. Sci., vol. PS-11, pp. 205-215, Sept. 1983). Electron trajectories are like those in magnetrons.

Magnetic insulation also assumes conductive paths at the ends of electrodes to allow electron current to flow from anode to cathode to complete the circuit.

The insulated electron flow (see [2] above) in the anode-cathode gap interacts with slow, transverse waves generated in the periodic rectangular corrugated CTL. With each cavity a shorted radial transmission line ([3] Leon Brillouin, "Wave guides for slow waves," J. Appl. Phys., Vol. 19, pp. 1023-1041, Nov. 1948).

HIGH POWER NONRESONANT VIRTUAL CATHODE OSCILLATOR

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Virtual Cathode Oscillators (Vircator) have been demonstrated to emit short pulses of very high power microwaves, ranged up to several gigawatts. The mechanism for the emission of the radiation has been attributed to both space and time oscillation of the virtual cathode and the oscillation of electrons in the potential well between the real and virtual cathodes (reflexing electrons). Vircators are also known to emit a wide band spectrum. Narrow band spectrum in Vircators can be achieved by a resonant cavity structure. Operation of Vircators is characterized by a single pulse of relatively low efficiency. However, its high power and relative simplicity makes the Vircator a useful source in HPM laboratories, for the study of HPM coupling to various systems.

In this paper we present detailed studies of a nonresonant Virtual Cathode Oscillator with extremely narrow band spectrum, which is an inherent property of the source. The device will be described along with measurements of the relevant parameters. The measurements were carried out in the S-band using a mildly relativistic electron beam with currents close to the critical current for pinching condition (0.5 - 1MV, 30-50 kA and pulse length of 50 nsec). Various techniques were used to measure the power and frequency of the microwave radiation. A high resolution pressurized calorimeter has been developed and used for measurements of the microwave power output. The calorimeter high sensitivity (50mV/J) and excellent signal to noise ratio makes it a very efficient tool for measurements of high power microwave. Maximum output power between 200-300 MW was achieved when the cathode surface design, charge voltage and anode-cathode gap are arranged to simultaneously maximize the diode voltage, satisfy magnetic insulation and avoid nonuniform and unstable electron emission.

Frequency measurements using a heterodyne mixer clearly indicate that the virtual cathode oscillates at a single frequency (~3 GHz) with a narrow bandwidth (<2%). The customary chirping behavior exhibited by a nonresonant Vircator oscillator is absent in these measurements. The central frequency follows roughly the beam plasma frequency and can be perfectly tuned by varying the diode voltage and anode-cathode gap. Microwave-induced gas breakdown indicates clearly that the dominant waveguide mode is TM_{01} mode.

Phase-Locking of Strongly Coupled Relativistic Magnetrons

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Abstract

Phase-locking of two strongly coupled S-band relativistic magnetrons in the gigawatt regime has been achieved. A single high voltage pulser drives the two relativistic magnetrons connected by a short waveguide of length $l \simeq n\lambda/2$. The time required to lock is $\simeq$ 7 ns. Phase-locking lasts for $\simeq$ 15-20 ns. Phase-locking in the π and 2π modes are demonstrated by direct phase measurement. The rms peak power is $\simeq$ 1.6 GW in the π mode and 400 MW in the 2π mode. Power density enhancement due to source coherence is directly measured in the radiation field. Locked phase measurements agree with phenomenological modelling of the experiment using a simple Van der Pol model.

ON THE USE OF THE HILBERT TRANSFORM FOR PROCESSING MEASURED CW DATA

F.M. Tesche
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Dallas, TX, USA

The Hilbert transform is a commonly used technique for relating the real and imaginary parts of a causal spectral response. It is found in both continuous and discrete forms, and is widely used in circuit analysis, digital signal processing, image reconstruction and remote sensing. One useful application in the area of high power microwave (HPM) technology is in correcting measured continuous wave (CW) transfer function data to insure causality in reconstructed transient responses. Another application of the Hilbert transform is in the area of complex spectral estimation using magnitude-only data.

In this paper, the theoretical basis for the Hilbert transform is briefly reviewed, and the numerical methods used for computing the transforms are discussed. In the evaluation of the Hilbert integral, there is an apparent singularity of the integrand, and this must be treated carefully.

Applications of the transform to several specific problems are then discussed. The so-called minimum phase reconstruction of a complex-valued spectrum using magnitude-only data is a common application of the Hilbert transform. This problem is examined for both real system data and analytically-derived spectral data, and possible errors in the resulting reconstructed transient waveforms are illustrated. It is shown that the minimum phase reconstructed transient waveform can be significantly different from the "real" waveform.

The use of the Hilbert transform for spectral filtering is also discussed. When measuring CW spectral data, or when computing CW responses using a measured transfer function, errors in the measurements can cause the resulting spectrum to correspond to that of a non-causal signal. The Hilbert transform may be used to filter the CW spectrum to insure causality in the reconstructed response. This technique is discussed and illustrated with examples.

Friday AM1 URSI-E, NEM Session FA12

Room: Columbus I/J *Time*: 0820-1000

Hybrid CW Simulators

Chair: Cinzia Zuffada, Kaman Sciences Corporation

0820 **TOPOLOGY for TRANSMITTING LOW-LEVEL SIGNALS from GROUND LEVEL to ANTENNA EXCITATION POSITION in HYBRID EMP SIMULATORS**
Carl E. Baum*, William D. Prather, Phillips Laboratory; Donald P. McLemore, Kaman Sciences Corporation

0840 **ELECTROMAGNETIC MODELING of LARGE LOOPS with CONCEALED DRIVE for REMOTE GAP FEED**
Cinzia Zuffada*, Kaman Sciences Corporation; Carl E. Baum, William D. Prather, Phillips Laboratory

0900 **TEST RESULTS for the PHILLIPS LABORATORY HIGH FREQUENCY CW SIMULATOR**
Tyrone Tran*, William D. Prather, Phillips Laboratory; Donald P. McLemore, Joe Martinez, Cinzia Zuffada, Kaman Sciences Corporation

0920 **AN EXPONENTIALLY TAPERED TRANSMISSION LINE ANTENNA**
N. H. Younan*, B. L. Cox, C. D. Taylor, Mississippi State University; William D. Prather, Phillips Laboratory

0940 **HIGH FREQUENCY ANALYSIS of the ELLIPTICUS ANTENNA**
N. H. Younan*, B. L. Cox, C. D. Taylor, Mississippi State University; William D. Prather, Phillips Laboratory

TOPOLOGY FOR TRANSMITTING LOW-LEVEL SIGNALS FROM GROUND LEVEL TO ANTENNA EXCITATION POSITION IN HYBRID EMP SIMULATORS

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In a typical hybrid EMP simulator there is a multi MV pulser above the ground, inserted in the resistively loaded wire-cage antenna. Suppose now one wishes to use a CW source over some broad band of frequencies in place of the high voltage pulser. This can be done by replacing the pulser with a CW source in the same (large, say a few meters in diameter) wire-cage antenna. Recognizing that for CW transfer functions one needs only low-level fields, and that efficiency in the sense of kV/m per MV in the pulser is not a problem, one can modify the design of the antenna. In particular the antenna could be a resistively loaded single wire with an equivalent diameter in the cm range.

Suppose one were to have the source on the ground and transmit the signal via a high-quality coax cable up to the old source location, perhaps with some matching network there to drive the antenna. Such a cable is a very large electromagnetic scatterer and, except under special symmetry conditions, will strongly perturb the fields produced in the test volume. The test volume needs to be far from this cable to avoid interaction with the test object. What is needed is a special kind of "wormhole" to make the cable effectively disappear for external scattering purposes. This can be approximately accomplished by alternating electric (conductor) and magnetic (choke) boundary conditions with suitably small spacing. Topologically the low-level source (CW or pulse) is fed from the earth surface up to the antenna feed position via a high quality coaxial cable. With the chokes suppressing the external cable-shield currents the source is moved to one of the connections of the hybrid antenna to the earth, while the loaded cable is moved to closely follow the path of hybrid antenna. Then transferring the resistors in the hybrid antenna to load the chokes (in parallel) it is observed that the loaded cable and the hybrid antenna can be one and the same.

There are limitations in the practical realization of this technique. The choke impedance has to be large compared to the loading R for frequencies of interest. At high frequencies the cable needs to be of sufficiently low loss for the length needed. Furthermore, there should be a sufficiently small spacing between chokes so that there are not significant resonances on the cable shield exterior.

ELECTROMAGNETIC MODELLING OF LARGE LOOPS WITH CONCEALED DRIVE FOR REMOTE GAP FEED

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Abstract

A new concept for a broadband low level hybrid EMP simulator has been investigated. It consists simply of a thin half loop of arbitrary shape, made of low loss coaxial cable, erected above the ground. Its original feature is in the feed: the signal is transmitted inside the cable from the RF source located on the ground to a remote point high above the ground where the cable outer conductor is cut open and an actual gap source is created. The current flows along the external surface of the conductor and through the ground, giving rise to EM fields. To give these fields the desired features of a plane wave at low frequency, proper resistive loading is achieved by placing RF chokes along the cable. Because the coupling is inductive the loading is effective on the external flow of current only, and does not interfere with the drive signal traveling inside the coaxial cable. A simple analytical model to calculate the fields produced by this antenna was developed, based on an asymptotic antenna theory for thin loops, which assumes that the ground is perfectly conducting. The load, although localized, is modeled as a frequency dependent impedance uniformly distributed along the antenna. Comparisons are presented between the calculations obtained from our simple, efficient code and experimental results, as well as calculations obtained with the NEC under consistent assumptions. The satisfactory agreement of the calculations from our model with NEC's and with experimental results indicate that we have developed a viable, efficient tool for field predictions of thin loops of arbitrary shape.

TEST RESULTS FOR THE PHILLIPS LABORATORY HIGH FREQUENCY CW SIMULATOR

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The Phillips Laboratory's low level CW illuminator which is described in two other papers*, was field mapped during the summer of 1991 in two basic configurations. One configuration was a notional twin catenary, the apex of the antenna being supported 20 meters in the air by ropes connected to telephone poles separated by 65 meters. The other configuration was a more elliptical shape with additional dielectric ropes supporting the antenna at regular distances to achieve the more elliptical geometry.

For the Twin Catenary configuration, the coaxial cables in each arm were connected to a fiber glass panel (approximately 1 meter x 1 meter) at the center and each of the arms was connected to a grounding rod at the earth-connected end. An resistive and inductive loading was used on the coaxial cable to control the impedance of the antenna as a function of frequency using 110 lower frequency torroids (material # 77-maganese/zinc) and 110 higher frequency torroids (material #43-nickel/zinc). To eliminate the need for a matching balun between the coaxial feed and the the antenna at the gap, a 50 ohm resistor was placed in parallel with the antenna. The Elliptical antenna was similarly configured with respect to ground connections and torroid loading.

Electric and Magnetic fields produced by these antennas were measured from 100 kHz to 200 MHz with a HP 3577 network analyzer and from 75 MHz to 1 GHz with an HP 8753C network analyzer within the working volume. The results illustrate relatively constant fields produced by these antennas over this frequency range in the working volume, which recommends its use as a CW simulator. This antenna was also used to measure both internal and external cable currents on a mobile communications system. Results from this test will also be presented.

*Baum, C., "Topology for Transmitting Low-Level Signals from Ground Level to Antenna Excitation Position in Hybrid EMP Simulators"

*Zuffada, C., Baum,.C. and Prather, W., "Electromagnetic Modeling of Large Loops with Concealed Drive for Remote Gap Feed"

AN EXPONENTIALLY TAPERED TRANSMISSION LINE ANTENNA

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ABSTRACT

For EMP applications, the illumination of large system structures should be uniform to be representative. However, radiative illumination tends to be highly nonuniform at frequencies where the test object characteristic dimension exceeds several wavelengths. Accordingly, an exponentially tapered transmission line antenna is designed to operate over the frequency range of 500 KHz to 1 GHz. This antenna has radiator characteristics at high frequencies and serves as a matching section at low frequencies.

The high frequency analysis is accomplished by using numerical techniques. Since transmission line theory does not account for radiation, the NEC-2 computer code is used to model only a portion of the exponentially tapered transmission line structure where electrically short straight wires segments are used to model the structure. Accordingly, a Thevenin model is used to replace that section of the structure. The Thevenin voltage and impedance are obtained via transmission line theory.

The evaluation of the design of the exponentially tapered antenna is obtained in terms of the input impedance and the radiation pattern of the antenna over the desired frequency range. For an open circuit termination, transmission line theory yields an input impedance that is purely imaginary. However, the numerical solution yields, in addition, a resistive component that is proportional to the radiated power for a constant input current. This is expected since the numerical solution includes radiation effects. Although the input impedance exhibits resonant peaks, the variation with frequency is appreciably smoothed. Also, as the frequency increases, the corresponding pattern calculations indicate that the transition section becomes an effective radiator.

HIGH FREQUENCY ANALYSIS OF THE ELLIPTICUS ANTENNA

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ABSTRACT

Present EMP test facilities, in general, do not provide the required high frequency illumination. Accordingly, a low level CW facility that incorporates the Ellipticus antenna is used to provide a horizontally polarized electric field to illuminate test objects. The original design specifications for the Ellipticus are provided such that it operates over the frequency range of 10 KHz to 100 MHz. Upgrading the Ellipticus to cover frequencies up to 1 GHz is accomplished by using a transition section from the driver to the antenna. The transition section is needed for impedance matching and for driving efficiently the Ellipticus antenna.

Due to the wide operating frequency range, a numerical rather than an analytical analysis of the Ellipticus illuminator is required. Accordingly, a procedure that incorporates the use of the NEC-2 computer code is used to examine the electromagnetic fields that can be developed in the working volume of the Ellipticus antenna. A parametric study is performed to ascertain the performance of the antenna for frequencies up to 1 GHz.

In the NEC modeling of the Ellipticus illuminator at high frequencies, i.e., 200 MHz and up, the entire transition section is replaced by its Thevenin model due to the large structure to be analyzed and to the limitations of the wire spacing in the NEC code. For frequencies below 200 MHz, the transition section is modeled with straight wires up until the wire spacing approaches 4 or 5 wire radii. Thevenin model is then used for the remaining length of the transition section.

The NEC results obtained from modeling the Ellipticus illuminator over a lossy ground plane indicate that the amplitude of the current decreases rapidly with distance from the driving point at high frequencies. Moreover, field uniformity is achieved within the working volume of the Ellipticus antenna.

Friday AM2 URSI-E, NEM Session FA16

Room: Columbus I/J *Time*: 1020-1220

EMP and HPM Simulation

Chair: C. D. Taylor, Mississippi State University

1020 **NEW GENERATION of BROADBAND GIGAHERTZ FIELD SIMULATORS**
Andrew S. Podgorski*, National Research Council of Canada

1040 **CW FIELD MAPPING of the SWISS EMP SIMULATOR MEMPS for PREDICTION of PULSE DATA**
Bruno Brandli*, E. Dorr, B. Reusser, Markus Nyffeler, NC Laboratory; Frederick M. Tesche, Electromagnetics Consultant

1100 **PREDICTION of the E and H FIELDS PRODUCED by the SWISS MOBILE EMP SIMULATOR (MEMPS)**
Frederick M. Tesche*, Electromagnetics Consultant; Bruno Brandli, Markus Nyffeler, NC Laboratory

1120 **100 MHZ - 4 GHZ NEAR-FIELD FACILITY for COUPLING CROSS-SECTION MEASUREMENTS**
J. C. Bolomey*, Ecole Superieure d'Electricite; G. Cottard, Satimo; D. Serafin, Centre d'Etudes de Gramat

1140 **MEASURED VARIATION of RF FIELD AMPLITUDES INSIDE ENCLOSURES**
Paul Tsitsopoulos, William Slauson*, Llewellyn Jones, Raytheon Company

1200 **FACILITIES for RADIO FREQUENCY SUSCEPTIBILITY TESTING**
Jeffrey E. Casper*, SRI International

NEW GENERATION OF BROADBAND GIGAHERTZ FIELD SIMULATORS

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Over the years, the Electromagnetic Field Protection Community has developed many methods for the measurement of radiated susceptibility and radiated emission. The widely used measuring methods rely on facilities that were developed over the last 50 years. These facilities constitute a tremendous asset that cannot be replaced with just another concept. For that reason it was the intention of the author to enhance the existing facilities, by proposing unifying modifications that will broad-band the measuring capability of currently existing facilities.

The development of the Broadband Gigahertz Field (BGF) Simulator is based on a hybrid concept, as it consists of a parallel line simulator and a broadband horn antenna. The parallel line simulator provides a uniform TEM field under the septum at frequencies extending from DC to about 300 MHz. At frequencies below 300 MHz the resistors at the end of the septum provide for the termination. At frequencies higher than 300 MHz, most of the field in the testing area is supplied by the broadband horn. The electromagnetic field is very well focused into a narrow 20% cone of radiation that is terminated with a wall covered by absorbing material. However, if the energy leakage is not a problem the absorbing wall can be removed and the septum can be terminated to the ground. The BGF Facility concept assures that all of the currently used facilities, except for Reverberation Chambers and TEM cells, can be modified into a BGF Facility. Modification performed on an Open Area Facility will reduce the noise level by 20 dB and will lower the environmental radiation impact by the same amount. The proposed modification will result in better electromagnetic field confinement, which in turn will be beneficial to a Weather Protected Open Area Facility. Because of better field confinement in the simulator, the metallic building can be used as a weather protector. For that reason, the EMP and EMC testing of an aircraft can be done in existing hangars without being concerned that noticeable degradation in electromagnetic field uniformity exists.

The greatest advantage of the use of BGF simulator can be observed when the BGF simulator is incorporated into an Anechoic Chamber. Such a design provides for a field uniformity of ±4 dB, which is considerably better than the ±6 dB field uniformity obtained for a BGF simulator used in an Open Area Test Facility. The use of the BGF simulator in Shielded Rooms and Anechoic Chambers also assures low background noise level and low emission level. The use of the BGF simulator with an Anechoic Chamber will permit simulation of both horizontal and vertical polarities.To summarize, the BGF simulator is the only field simulator that provides broadband simulation for both vertical and horizontal polarizations.

CW FIELD MAPPING OF THE SWISS EMP SIMULATOR MEMPS FOR PREDICTION OFPULSE DATA

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The fields in the working volume of an EMP simulator are usually described by field-map data. Several problems, however, make an accurate description of these fields difficult. Pulse-to-pulse variations of the pulser output must be taken into account by measuring the field for each shot at a suitable reference point. In addition, the pulse shape depends, to some extent, on the operating voltage of the pulser and other pulser settings. A more accurate way of determining the working volume field on a shot-by-shot basis is to use the measured reference fields, and calculate the field components at a desired location in the working volume with the help of field transfer functions.

As the Swiss MEMPS simulator can be modified to operate in a CW mode, a CW field-mapping was conducted to directly measure the field transfer functions from the reference point to selected points in the working volume. Using these CW transfer functions, the working volume transient fields were calculated, based on the measured transient fields at the reference location. A comparison of these results with measured transient fields at the same locations shows a fairly good agreement.

The measured CW transfer functions are also used to analyze some properties of the simulator and its environment, such as structural symmetry, waveform reflections, antenna resonances, etc. To conclude, it may be stated that these CW measurements yield a good description of the pulsed simulator fields, including the effects arising from the simulator surroundings.

PREDICTION OF THE E AND H FIELDS PRODUCED BY THE SWISS MOBILE EMP SIMULATOR (MEMPS)

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AC Laboratory Spiez, Switzerland

It is often necessary to test critical systems for hardness against electromagnetic (EM) field threats such as an electromagnetic pulse (EMP). To this end, a number of full-scale, threat-level simulators have been developed to permit system-level testing. Typically, these simulators produce an EM field within a specified "working volume" of the simulator. Of key importance in the simulator design and its use is the accurate knowledge of the EM fields within this volume. These fields are usually measured before a test, in an activity referred to as a "field mapping." This can be a time consuming and expensive proposition.

An alternative to a detailed field mapping procedure is to measure the field at one or several reference points. These limited measurements are then to calculate the fields at other locations within the working volume using a suitable calculational model. In this manner, the details of the pulser source waveform, such as amplitude and rise-time are taken into account in determining the simulator fields.

This paper discusses the application of this concept to the Swiss Mobile EMP Simulator (MEMPS). A simple transmission line analysis procedure for determining the electromagnetic fields radiated by the simulator is described. The currents flowing on the simulator structure are first obtained. This takes into account both the resistive loading along the simulator and the dispersive nature of the lossy earth under the simulator. Once this current distribution is determined, the fields at an arbitrary location are determined by integrating the fields produced by an electric current element located over a lossy air-earth interface. As will be shown in the paper, results from this calculation compare favorably with both measurements and other results using a different modeling approach.

Using this modeling approach, a technique to accurately calculate the transient field at an arbitrary location within the simulator is described. This requires a knowledge of the primary **E** and **H** field components at a reference point near the simulator, or equivalently, a knowledge of the incident E or H field at this point. Results of this limited study indicate that it is possible to predict the simulator fields at other points, based on the reference fields and the calculational model.

100 MHz - 4 GHz NEAR-FIELD FACILITY FOR COUPLING CROSS-SECTION MEASUREMENTS

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Understanding coupling mechanisms and determining coupling cross-sections (CCS) are of prime importance in view of hardening processes. Most of time, CCS are determined directly from a convenient illumination of the test object, in a simulator or in free-space. As well known, a reciprocal approach consists of considering the test object as a transmitting antenna. Indeed, it can be shown that the CCS of an object in a given direction is proportional to its radiation pattern in the same direction. As it is usual in antenna practice, far-field (FF) patterns can be derived from near-field (NF) measurements by means of NF to FF transformations. Two advantages of this indirect approach with respect to the direct one are 1) to avoid plane wave illumination over a broad frequency band, and 2) to provide increased flexibility to simulate arbitrary polarization state and incidence angle. For these reasons, a NF facility has been designed for microwave CCS measurements, in a broad frequency band extending from 100 MHz to 4 GHz. The spherical geometry has been selected to accomodate poorly directive radiating objects. In the upper part of the frequency band, from 1 GHz to 4 GHz, NF measurements are performed by means of a semi-circular array of 128 dual-polarized probes. Such an array allows to drastically speed up the probing process. The radius of the array is equal to 2 meters. Each probe consists of two orthogonal short dipoles loaded by a PIN diode, modulated at a low frequency rate according to the modulated scattering technique (J.Ch.Bolomey et al., IEEE Trans. AP-36, 804-814, 1988). Rapid NF data are obtained while the test object is continuously rotated. After only one revolution, the whole NF distribution on a sphere has been measured, from which FF patterns can be derived in arbitrary cuts. The lower part of the frequency band, from 100 MHz to 1 GHz, is covered by classical single-probe scanning technique. In that case, the probe is mechanically moved along a semi-circular arc. This NF spherical arrangement is located in an anechoïc chamber, the external dimensions of which are 10 m X10 m X 8 m. This paper describes the performances and the capabilities of this NF facility, and presents some preliminary results obtained with generic objects of simple shapes.

MEASURED VARIATION OF RF FIELD AMPLITUDES INSIDE ENCLOSURES

Paul Tsitsopoulos, William Slauson*, Llewellyn Jones
Equipment Division, Raytheon Co.

The penetrating RF field levels in different locations within enclosures can vary by an order of magnitude or more. The internal structures impose complex resonant behavior on the leakage, causing order of magnitude changes within small frequency ranges. These variations along with those for orientation will cause great variations in the induction in any exposed interconnects within the enclosure. Consequently, estimates of RF induction for HPM evaluations must include a large error bar to account for field variations. An experiment showed these large variations.

Two relatively generic enclosures, a rectangular "box" and a sphere, were tested for RF penetration from 0.85 to 12.4 GHz. They had seams, apertures, and attached cables. The sphere had a covered port as the main point of entry and was relatively empty inside. The box had seams around the connectors as the main points of entry and had many metallic partitions inside. Both were tested in several orientations to the RF source and in two basic conditions, normal and "sealed" with copper tape. B-dot probes were used to measure the magnetic fields. All measurements were made relative to the incident fields; i.e., shielding effectiveness (SE) was measured.

The results showed that both resonances and location can change the internal fields by an order of magnitude. Even the relatively empty sphere showed very fine resonant structures in the SE spectrum. The resonances were greatly reduced by placing some RF absorbing material inside. The cover on the port was ineffective in maintaining SE in lower spectral regions. The box showed an order of magnitude change in field with probe location. The orientation of the box or sphere caused at least half an order of magnitude of change in field. Sealing each with copper tape proved effective only with the main points of entry. These results illustrate the large variations in internal fields caused by location, resonances, enclosure orientation, and condition of points of entry. RF field levels can vary by 2.5 orders of magnitude just due to location, orientation and resonances.

FACILITIES FOR RADIO FREQUENCY SUSCEPTIBILITY TESTING

Jeffrey E. Casper, SRI International, Menlo Park, California

This talk will review the various types of facilities that can be used to evaluate the radio frequency (RF) susceptibility of electronic equipment. The advantages and limitations of each type of facility will be discussed. The facilities considered include:

- Anechoic chambers
- Reverberation chambers
- TEM cells and tapered TEM cells
- Open area test sites
- Stripline test facilities
- Direct drive facilities
- Special RF facilities.

The parameters of interest for these facilities include the usable frequency range, the capability for continuous wave (CW) and/or pulse exposure, and the ability to provide free-field illumination.

Anechoic chambers and open area test sites simulate free space propagation, can illuminate large test objects, and can be used for either CW or pulsed operation within certain practical limits. Reverberation chambers (also known as mode-stirred chambered) allow the simultaneous testing of frequencies, angles of illumination, and polarizations, but the system response is not relatable to the source specifics. Its value is in the identification of frequencies of concern, for which additional testing would be warranted. Tapered TEM cells provide a well-controlled, uniform RF environment and are useful for small test objects. Stripline and direct drive test facilities provide high field strengths and input powers from limited energy sources. Their usefulness is in maintenance and surveillance efforts.

A brief description of the design and capabilities of the SRI Microwave Exposure for Damage and Upset Susceptibility Assessment (MEDUSA) facility will also be provided.

Friday PM AP-S, URSI-A B, NEM Session FP10

Room: Columbus G *Time*: 1320-1700

Electromagnetic Properties of Materials

Organizers: R. Mittra, University of Illinois, Urbana-Champaign; Richard G. Geyer, National Inst. of Standards & Technology

Chairs: R. Mittra, University of Illinois, Urbana-Champaign; Richard G. Geyer, National Inst. of Standards & Technology

1320 **THE DETERMINATION of DIELECTRIC PROPERTIES at NEAR MILLIMETRE WAVELENGTHS**
J. R. Birch*, National Physical Laboratory

1340 **MICROWAVE CHARACTERIZATION of HIGH-Tc SUPERCONDUCTING THIN FILMS and DEVICES**
W. G. Lyons*, D. E. Oates, MIT Lincoln Laboratory

1400 **BROADBAND MICROWAVE DIELECTRIC MEASUREMENTS with OPTOELECTRONICALLY GENERATED PICOSECOND TRANSIENT RADIATION**
G. Arjavalingam*, IBM Research Division

1420 **MICROWAVE TECHNIQUES for MEASUREMENT of RADAR ABSORBING MATERIALS-- a REVIEW**
Genevieve Maze-Merceur*, J. L. Bonnefoy, J. Garat, CEA-CESTA; R. Mittra, University of Illinois, Urbana-Champaign

1440 **MICROWAVE CHARACTERIZATION of FERRITES**
Richard G. Geyer*, James Baker-Jarvis, National Inst. of Standards & Technology

1500 **Break**

1520 **THEORY of MEASUREMENT of the CONSTITUTIVE PARAMETERS of CERTAIN MAGNETOELECTRIC MEDIA**
T.-T. Kao, P. L. E. Uslenghi*, University of Illinois at Chicago

1540 **ESTABLISHMENT of EMPIRICAL MODELS for LOW-LOSS DIELECTRICS**
K. Fidanboylu*, H. Geramifar, Ioannis M. Besieris, Sedki Riad, Virginia Polytechnic Inst. & State Univ.

1600 **MEASUREMENT of ELECTROMAGNETIC PROPERTIES of ABSORBING MATERIALS in the AEROSPACE INDUSTRY: ISSUES and (SOME) ANSWERS**
D. A. Luippold*, Northrop Corp.; K. M. Mitzner, Northrop Corporation; D. S. Hunzeker, W. Hant, F. J. Murray, Northrop Corp.

1620 **MEASUREMENT of MICROWAVE DIELECTRICS: EXPERIENCE, NEEDS and IDEAS**
G. R. Traut*, Rogers Corporation

1640 **A QUASI-CLASSICAL, LINEAR KINETIC THEORY for a FERRIMAGNETIC MEDIUM-LINEAR MAGNETIZATION**
Robert A. Schill, Jr.*, University of Illinois at Chicago; John M. Tischer, Motorola, Communications Sector

THE DETERMINATION OF DIELECTRIC PROPERTIES AT NEAR MILLIMETRE WAVELENGTHS

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Abstract

There are several important scientific and technological reasons why accurate knowledge of the optical or dielectric constants of solids are required in the near millimetre wavelength region of the electromagnetic spectrum between about 1 cm and 0.3 mm. First, interests in radar, telecommunications, remote sensing and surveillance applications will create their own design requirements for quantitative knowledge of the frequency variation of these constants. Second, the general increase in the use and application of near millimetre wave techniques in areas of potentially important developments such as fusion plasma diagnostics and biological studies points to a requirement for standard reference materials. These would be specimens of known dielectric properties for use in the calibration of spectrometers in order to assess levels of measurement error. Third, the detailed origins of many loss mechanisms at near millimetre wavelengths are poorly understood. Accurate knowledge of the frequency dependence of the real and imaginary parts of the complex permittivity would permit a detailed evaluation of various models of such loss processes. This improved understanding of the microscopic charge transport dynamics of materials should point to advances in areas of technological and industrial interest.

The presentation will review those methods which are presently being used for dielectric measurements on solids at near millimetre wavelengths over a range of temperatures from 4.2 to values in excess of 1500 K. The methods will include both resonant and non-resonant techniques, and monochromatic and broad band ones. There will be some discussion of the results of a recent intercomparison exercise in which a number of such techniques were used in a study of the dielectric properties of a group of specimens.

MICROWAVE CHARACTERIZATION OF HIGH-T_c SUPERCONDUCTING THIN FILMS AND DEVICES

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Development of high-transition-temperature (T_c) superconducting thin-film microwave components has progressed dramatically over the past five years following the discovery of $YBa_2Cu_3O_{7-x}$ (YBCO) in 1987. This material is a member of a new class of superconductors with transition temperatures higher than the boiling point of liquid nitrogen. Although other superconducting materials with higher transition temperatures have been produced since 1987, most efforts toward device fabrication have focused on YBCO because of the comparative ease with which single-phase material can be grown. A very successful microwave application for high-T_c materials has been planar passive components such as resonators and filters which take advantage of the low loss of superconductors.

The high-frequency surface resistance R_S of high-T_c thin films is typically determined by measuring loss (or quality factor Q) in a resonator and then accounting for the current distribution in the film so that an equivalent surface resistance for a semi-infinite-thick slab can be calculated. A stripline resonator has been the characterization tool of choice at Lincoln Laboratory, although other resonators and cavity techniques can also be used. The best R_S values obtained in this work for YBCO at a frequency of 1.5 GHz are $2.6 \times 10^{-6}\ \Omega$ at 4 K and $8.3 \times 10^{-6}\ \Omega$ at 77 K. The surface resistance depends on power, not only because of the nature and quality of the superconducting film, but because the design of the device will affect current distribution. In particular, current crowding at the edge of transmission lines produces a nonlinearly increasing R_S with increasing power, and this, in turn, leads to the generation of harmonics, intermodulation products, and reduction of the Q. In linear device applications, power levels must be selected to avoid such nonlinear effects. Noise generated by nonlinearities and other mechanisms is also an important consideration. This talk will summarize the current state of reported R_S measurements.

Many passive high-T_c microwave components have been demonstrated thus far, including narrowband filters for frequency multiplexers, chirp filters for real-time multigigahertz spectrum analysis, delay lines for analog memory storage, resonators for oscillator stabilization, and superconductive feed networks for microstrip antenna-patch arrays. An overview of the results obtained at Lincoln Laboratory for each of these components will be presented. Performance of each component must be carefully characterized for loss, accuracy, power-handling capability, intermodulation, and noise because of the impact on the corresponding microwave subsystem performance.

High-T_c superconducting components will have a substantial impact on microwave systems. Depending on the frequency of operation, superconductors provide many orders of magnitude lower loss than equivalent metallic components. For many types of devices and systems, this lower loss enables system performance that would otherwise be unattainable. Integration of high-T_c passive components into microwave receiver subsystems for actual field demonstrations is now beginning, and convincing applications are promised within this decade.

Broadband Microwave Dielectric Measurements with Optoelectronically Generated Picosecond Transient Radiation

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The recently developed coherent microwave transient spectroscopy (COMITS) technique will be described and its application to the characterization of the complex dielectric properties of materials, in the 15 - 140 GHz frequency range, will be presented (G. Arjavalingam et al., Trans. MTT, Vol. 38, p 615, 1990). The COMITS technique is based on freely propagating electromagnetic pulses radiated and received by broadband antennas which are integrated with high-speed optoelectronic devices. Ultrashort optical pulses are used to generate the picosecond-duration electrical pulses which drive the antennas and also to photoconductively sample the received waveforms. No traditional microwave sources or detectors are used in the experiment. The spectrum of the transient radiation has components extending up to 150 GHz and vanishes towards zero frequency. Since the measured time-dependent waveform is proportional to the received field, phase information is preserved. In order to characterize a given material two waveforms are recorded with two different sample thicknesses. The time-domain data are Fourier transformed and the corresponding spectra are divided to eliminate the effect of the sample surfaces and to extract the net contribution due to the bulk. The real part of the dielectric constant is calculated from the net phase delay, and the loss coefficient from the reduction in amplitude. Consequently, the complex dielectric constant of the material is determined over the wide available bandwidth, in a single experiment.

The COMITS experimental set-up has been used to characterize low-loss materials such as Teflon, and materials of interest to the digital electronics industry such as Polyimide and ceramics. Recently, it has been extended to characterize the properties of thin polymer films and also to explore the dispersion properties of novel photonic-band structure (PBS) samples. The radiation is highly polarized facilitating the characterization of anisotropic material properties. These include crystals such as Sapphire and Quartz, and anisotropic conductors such as some conducting polymers.

In addition to the transmission experiments, we have also developed a reflection-COMITS configuration to characterize lossy materials such as doped semiconductors. The same set-up has been used to study the scattering of pulses by three-dimensional objects.

MICROWAVE TECHNIQUES FOR MEASUREMENT OF RADAR ABSORBING MATERIALS -- A REVIEW

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The characterization of radar absorbing materials is of great interest in a number of microwave and millimeter-wave applications. Examples include reduction of clutter due to multipath reflections from buildings and structures; minimization of radiations pattern perturbations due to coupling between antennas and their environment; and stealth applications for RCS reduction of radar targets. The synthesis of absorbing screens typically leads to requirements for specific material properties, i.e., complex permittivities and permeabilities, for the various layers. It is essential to be able to measure the properties of the materials in the frequency range of interest with good accuracy to ensure that the synthesized screen would indeed perform as designed. It is also necessary to be able to do this for various ranges of temperature. The characterization of the complex permittivity and permeability, ε and μ, is carried out in different environments, e.g., in transmission lines and waveguides, in resonant cavities, or in free space, depending upon whether the material is thick or thin, homogeneous or inhomogeneous, and isotropic or anisotropic. Whatever the approach, it is essential that the method of measurement be efficient enough to handle a large variety of manufactured samples from which the final selection of the materials is to be made.

In this paper, we begin by describing the transmission line approach, used in conjunction with a network analyzer, to measure the complex values of ε and μ of homogeneous as well as heterogeneous, but isotropic and thick samples. For biaxial samples, we present a method that uses a guided-wave structure with a preferential axis, such as a coaxial line or a waveguide of rectangular cross-section. Next we turn to the problem of measuring the permeability of anisotropic thin films by using a loop, the extraction of μ from the knowledge of the flux variation, and the validation of these results by comparison with theoretical values of μ vs. frequency that can be computed from the static measurements (VSM). This is followed by a discussion of the single frequency measurement techniques, based on cavity resonance perturbation approach, for accurate characterization of small samples.

Finally, we turn to the free space techniques that are useful for the measurement of anisotropic and heterogeneous materials. Typically, free-space mesurements are carried out in anechoic chambers, involve both the reflection and transmission measurements, and yield information on absorption and surface impedance characteristics of the sample. This information is useful for designing the shape as well as the coating of complex targets with a view to reducing their RCS.

In situ measurements for validating such low-observable designs are also described in the paper.

MICROWAVE CHARACTERIZATION OF FERRITES

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Abstract

With continued advances in microwave and millimeter-wave theory and computer technology, computer-aided design plays an important role in the development of ferrite devices. In order to utilize these advances, it is necessary to have accurate broadband spectral characteristics of ferrite materials. This presentation is limited to magnetic spectra of polycrystalline ferrites for several reasons. First, satisfactory ferrite monocrystals are difficult to grow and produce. Second, the perfection and regularity of monocrystals make it difficult to observe important resonance phenomena due to domain walls and the influences of internal demagnetizing fields on relaxation behavior due to domain rotations. Finally, major microwave applications of ferrites still involve sintered polycrystalline materials. Ferrite electromagnetic properties may be anisotropic and nonlinear. In the presence of an externally applied dc-bias field or in the case of a significant internal anisotropy field, the behavior will be non-reciprocal, and the permeability must be described as a tensor rather than scalar. The emphases in this investigation are on the techniques by which accurate, constant- temperature complex permeability and permittivity measurements can be made, as well as on the construction of physical models which spectrally characterize ferrite permeability variation. Magnetic loss mechanisms due to classical hysteresis, domain-wall motions, and gyromagnetic resonance are examined, and differential uncertainty analyses which treat sources of measurement error are performed.

THEORY OF MEASUREMENT OF THE CONSTITUTIVE PARAMETERS OF CERTAIN MAGNETOELECTRIC MEDIA

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We consider linear magnetoelectric (or bianisotropic) materials with constitutive relations in the frequency domain:

$$(1)\quad \underline{D} = \varepsilon_o \bar{\bar{\varepsilon}}\, \underline{E} + c_o^{-1} \bar{\bar{\xi}}\, \underline{H}\ , \qquad \underline{B} = \mu_o \bar{\bar{\mu}}\, \underline{H} - c_o^{-1} \bar{\bar{\eta}}\, \underline{E}\ ,$$

where $\bar{\bar{\varepsilon}}$, $\bar{\bar{\mu}}$, $\bar{\bar{\xi}}$ and $\bar{\bar{\eta}}$ are dimensionless tensors represented by 3 x 3 matrices in the rectangular (x, y, z) coordinate system:

$$(2)\quad \bar{\bar{\varepsilon}} = \begin{pmatrix} \varepsilon_1 & 0 & 0 \\ 0 & \varepsilon_2 & 0 \\ 0 & 0 & \varepsilon_3 \end{pmatrix}, \quad \bar{\bar{\mu}} = \begin{pmatrix} \mu_1 & 0 & 0 \\ 0 & \mu_2 & 0 \\ 0 & 0 & \mu_3 \end{pmatrix}, \quad \bar{\bar{\xi}} = \begin{pmatrix} 0 & \xi_4 & 0 \\ \xi_5 & 0 & \xi_6 \\ 0 & \xi_7 & 0 \end{pmatrix}, \quad \bar{\bar{\eta}} = \begin{pmatrix} 0 & \eta_4 & 0 \\ \eta_5 & 0 & \eta_6 \\ 0 & \eta_7 & 0 \end{pmatrix}.$$

Several interesting materials have constitutive relations which are particular cases of (1,2). The case $\xi_6 = \xi_7 = \eta_6 = \eta_7 = 0$ has been previously studied: the measurement of constitutive parameters has been discussed (P.L.E. Uslenghi, Proc. ICEAA'91, pp. 149-151, Turin, Italy, Sept. 1991) and the propagation in slab waveguides examined (J.D. Ali and P.L.E. Uslenghi, Nat. Radio Science Meeting, Boulder, CO, Jan. 1992). Propagation in slab waveguides for the more general case (1,2) will be presented (URSI Intnl. Symp. on Electromagnetic Theory, Sidney, Australia, Aug. 1992).

The determination of the consitutive parameters (2) is considered when a slab of material with planar boundaries at $z = 0$ and $z = d$ is available. If the slab is sufficiently large, free-space measurements may be possible; hence, we study the case of a linearly polarized plane wave incident on such a slab, and extract as much information as possible on the constitutive parameters from the measurements of amplitude and phase of the reflection and transmission coefficients.

When the sample cannot be made sufficiently large, other types of measurements must be conducted. Firstly, we examine what information can be extracted by measuring reflection and transmission coefficients for a sample inserted in a rectangular waveguide. Secondly, we consider measurements in a stripline configuration.

A general conclusion is that no single experimental setup can provide all the information needed to solve this inverse problem. Hence, several measurements utilizing different experimental setups must be conducted on the same material.

ESTABLISHMENT OF EMPIRICAL MODELS FOR LOW-LOSS DIELECTRICS

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An overview of existing empirical dielectric models, as well as trends for establishing new ones, is presented. The ultimate goal is to develop models that provide physical representations for low-loss dielectrics that are applicable over a wide frequency spectrum. The commonly used Debye model for the complex dielectric permittivity has been shown to be valid only for some liquid dielectrics. The dielectric behavior of more general materials, especially solids, departs from the Debye representation drastically. In order to obtain more accurate representations for a general group of materials, several researchers, such as Cole-Cole, Davidson-Cole, Havriliak-Negami, Nakamura-Ishida, Jonscher, Fuoss-Kirkwood and Hill, have attempted to obtain empirical models by modifying the basic Debye representation.

Later on, Shin-Yeung have shown that the Debye model as well as the empirical models developed by the above researchers satisfy a non-linear differential equation having the following property:

$$Q(Q(F)) = k\, Q(F)$$

where, Q is the non-linear differential operator, k is a proportionality constant, and F is the susceptibility spectral shape function. The solution to this non-linear differential equation provides a guide for developing new empirical models that might be applicable for certain class of materials.

In order to investigate the spectral behavior of these models, several computer simulations have been performed. By using the Debye model as a reference, the empirical models available in the literature have been compared with each other. This comparison have revealed very useful information about the limitations of each model. As a result of these simulations and experimental data, in this paper, we discuss the validity of the existing empirical models for low loss dielectrics, especially for Polymer type materials.

MEASUREMENT OF ELECTROMAGNETIC PROPERTIES OF ABSORBING MATERIALS IN THE AEROSPACE INDUSTRY: ISSUES AND (SOME) ANSWERS

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An overview is given of electromagnetic measurements problems that arise in connection with the use of Radar Absorbing Material (RAM) in aerospace design and production. Some of the most successful and most promising measurement techniques are discussed. These include resonant stripline, waveguide, free space insertion loss, impedance measurement in a capacitive fixture, and Q-spoiling of a cavity. In many cases, a customary measurement procedure has had to be modified to take into account the special properties of the material under test, the necessity for data over frequency ranges where neither quasistatic nor high frequency techniques are convenient, and/or the special demands of a reliable quality assurance system for routinely checking bulk quantities of material. Accuracy and precision requirements vary from a few percent to stringent. The availability of modern network analyzers with supplementary custom software has greatly simplified the development and implementation of these materials characterization procedures.

One case history shows how a requirement to measure resistive sheet material at very high frequency (VHF) through a dielectric coating was satisfied by developing a network analyzer probe that couples capacitively to the sheet. This device exhibits some of the properties that are important to a practical industrial application: portability, robustness, ability to measure continuously along a run of material, and sensitivity to local material variations and defects.

MEASUREMENT OF MICROWAVE DIELECTRICS: EXPERIENCE, NEEDS AND IDEAS

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Abstract

For several decades foil clad laminates based on PTFE-based composites for microwave and mm-wave applications have seen extensive use where printed circuit technology has been exploited for producing microwave components and systems. The formats used include stripline, microstrip, coplanar waveguide, finline with variations on these. The most critical characteristic for success of almost any design is complex permittivity at the frequency of the application.

This characteristic must be monitored and controlled by supplier and user. We have lacked convenient standardized definitive methods with traceable reference specimens. The ASTM D3380 (IPC 2.5.5.5) stripline resonator method with its numerous limitations is in use along with some less convenient microstrip methods. A variety of possible methods see less use.

New compositions, many not based on PTFE, are finding their place. Some do not lend themselves to present measurement methods.

The permittivity of dielectric substrates cannot simply be considered independently of other parameters. Its relationship to temperature, frequency, electric field orientation needs to be understood. Its variability and the precision with which it can be determined are important.

Measurement methods are needed to satisfy several important goals in areas of convenience, specimen cost, relevance to the application, repeatability, traceability, cost and complexity of instrumentation. Some measurement methods are proposed but they need to be better understood and developed into standards.

A QUASI-CLASSICAL, LINEAR KINETIC THEORY FOR A FERRIMAGNETIC MEDIUM - LINEAR MAGNETIZATION

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An enormous amount of theoretical and experimental works in the area of magnetic mediums exist. The classical phenomenological approach is widely used by engineers. Quantum mechanics provides a more rigorous structure in the study of magnetic mediums. Such a description is very difficult if not nearly impossible to apply in practice. There are a variety of effects which can not be accounted for using a classical description. A classical kinetic theory modeling the effects of magnetic mediums does not exist and for good reason. In statistical mechanics, the phase space approach violates the Hiesenberg uncertainty principle since each phase point designates the exact state of the particle, magnetic ion. Even so, the correspondence principle stipulates under suitable limits that both classical and quantum theory must agree.

A self consistent, quasi-classical, linear kinetic theory adopting a six dimensional angular momentum/configuration phase space, is used to develop the linear magnetization for a finite, anisotropic, magnetic medium biased with a large, uniform, magnetostatic field. Only the classical dipole and quantum mechanical exchange interactions are incorporated into the theory. With suitable approximations, the equilibrium and linear magnetizations agree with existing theories. The ferrimagnetic medium is composed of two interpenetrating magnetic ion sublattices. The exchange interaction gives rise to transverse wave oscillations due to boundary effects. With exchange interaction, Maxwell's equations are of differential/integral form. The kinetic model and simple characterizations of the magnetization will be presented.

Friday PM1 URSI-E, NEM Session FP12

Room: Columbus I/J *Time*: 1320-1500

Guided Wave EMP Simulators

Chair: Frederick M. Tesche, Electromagnetics Consultant

1320 **DESIGN, CONSTRUCTION and CHARACTERIZATION of DREMPS**
M. Burton*, S. Kashyap, J. S. Seregelyi, P. Sevat, Defence Research Establishment Ottawa

1340 **A THREAT-LEVEL EMP SIMULATOR for SHIPS (EMPSIS)**
W. Pont*, J. J. A. Klaasen, TNO Physics and Electronics Laboratory

1400 **PRELIMINARY TEST RESULTS from INSIEME BOUNDED WAVE EMP SIMULATOR in ITALY**
P. Papucci, CRESAM; L. Bolla, AEITALIA; F. Pandozy, FACE; C. Noya, U. Sinibaldi, C. Cacciatore, ELMER; B. Augsburger*, K. Salisbury, Y. G. Chen, R. White, Maxwell Laboratories Inc.; D. Giri, PROTECH

1420 **CALCULATION of the RADIATED ELECTROMAGNETIC FIELDS from PARALLEL-PLATE EMP SIMULATOR**
Frederick M. Tesche*, Electromagnetics Consultant; Charles T.C. Mo, Logicon/RDA; William Shoup, Field Command, Defense Nuclear Agency

1440 **TIME DOMAIN INCIDENT-FIELD EXTRAPOLATION**
J. J. A. Klaasen*, TNO Physics and Electronics Laboratory

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Design, Construction and Characterization of DREMPS

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Defence Research Establishment Ottawa
Ottawa, Ontario, Canada
K1A 0Z4

This paper describes the design, construction and preliminary characterization of the Canadian Defence Research EMP Simulator (DREMPS). Figure 1 shows an artist's view of the bounded wave simulator. It is made from two sets of parallel wires to minimize ice and wind loading. The simulator is designed to produce a threat level EMP field of 50 kV/m within a working volume of 10m x 20m x 30m. This volume is large enough to accommodate a helicopter, tank or communication van. The facility has been designed with a helicopter pad to allow EMP assessment of heavy transportable equipment. Electromagnetic fields inside and around the simulator have been computed and an environmental assessment of the simulator regarding health, safety and interference has been done.

Preliminary measurements of both electric and magnetic fields inside and outside the simulator and time domain reflection (TDR) measurements have been made. As a result of these measurements, changes were made to the load end taper and the resistive load in order to minimize the reflections.

Details of the design, construction, and preliminary electromagnetic field and reflection measurements will be presented.

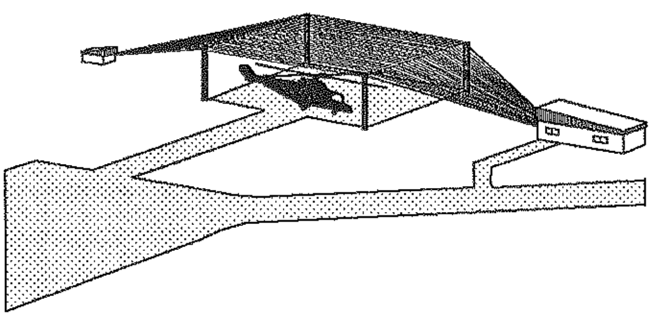

Figure 1. Artist's View of the DREMPS

A THREAT-LEVEL EMP SIMULATOR FOR SHIPS (EMPSIS)

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NEMP assessments on large ships have been carried out with the low-level simulator EMIS-3 in the Netherlands, for many years. Since 1982, the possibility of a full-threat level simulator for naval vessels has been discussed within a cooperation project between the United Kingdom, Norway and the Netherlands. A feasibility study was initiated by the navies of the mentioned countries in 1989. This study resulted in a small-scale experiment (simulator height 10m) with a parallel-plate simulator over sea water and at threat level, in Norway in 1990. The experiments showed that sea water can be used as part of the waveguide structure of the simulator.

In 1991 TNO-FEL got the task to draft the pulser specifications and to make a preliminary design for the transmission line of the simulator. The simulator, that was baptized as EMPSIS (ElectroMagnetic Pulse SImulator for Ships), must be able to test vessels up to 200m length and 46m height at threat level for both the old and the new exo-atmospheric-NEMP requirements.

Data for the design was gathered from the following experiments performed by TNO-FEL:

- Measurements in a 6m-high parallel-plate simulator connected to a 10kV/0.9ns pulse generator (1989),
- Measurements in a 10m-high parallel-plate simulator over sea water in Norway (1990, with participation of UK and Norway),
- Measurements in 10m-high parallel-plate and conical-plate simulators connected to a 10kV/0.9ns pulse generator (1991).

In this paper is referred to the results of these experiments. The expected rise time, pulse distortion, and the homogeneity of the generated field in the EMPSIS simulator will be highlighted. Some expectations are given about a fast-pulse generator and its ability to drive a transmission line with a rather low impedance.

PRELIMINARY TEST RESULTS FROM INSIEME BOUNDED WAVE EMP SIMULATOR IN ITALY

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F. Pandozy,	FACE, Rome, Italy
C. Noya, U. Sinibaldi, C. Cacciatore,	ELMER, Pomezia, Italy
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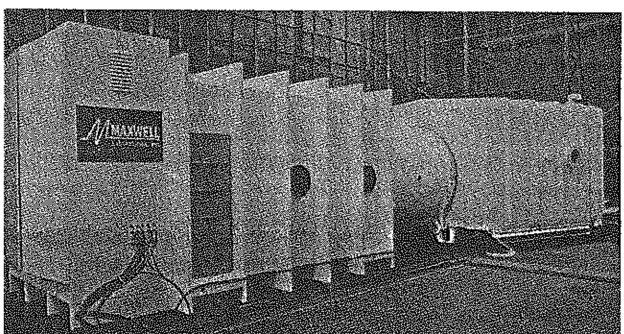
R. White,	
D. Giri,	PROTECH, Berkeley, CA. USA

Impianto Nazionale per la Simulazione di Impulsi Electro-Magnetici Esoatmosferici is a conical transmission type EMP simulator which was designed and built for CRESAM, near Pisa in Italy. In this paper we will present the preliminary test results for INSIEME which was conducted into a resistive load. This simulator has a 100 Ω TEM mode characteristic impedance which is excited by a 1.3 MV, < 5 nanosecond risetime pulse generator. Some aspects of the engineering design will be discussed such as the pulse power configuration and the coaxial to parallel plate transition. The expected Electromagnetic performance will be compared with the experimental test results.

The INSIEME EMP simulator has been tested with the customers presence (CRESAM, ELMER) at the MAXWELL facility in San Diego, California. The tests were conducted into a resistive dummy load with a nominal resistance of 100 Ω. The dummy load consists of four 400 Ω water resistors which are connected in parallel to a mock-up antenna extenstion. Using a mock-up antenna transition and connecting the dummy load resistors in a horizontal fashion provides the clear time (25 ns) necessary for conducting the Electromagnetic mesurements. The test series demonstrated the pulse power characteristcs such as Marx generator voltage, peaking capacitor voltage, and FWHM. The Electromagnetic field data was measured to determine the pulse risetime and field amplitude. INSIEME will be tested into the CRESAM antenna during the summer of 1992.



CALCULATION OF THE RADIATED ELECTROMAGNETIC FIELDS FROM A PARALLEL-PLATE EMP SIMULATOR

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Dallas, TX

Charles T.C. Mo
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Recent concerns about the environmental and biological effects of radiated electromagnetic (EM) fields have lead to an increased awareness desire to predict and control such fields at locations far from their source. For system-level electromagnetic pulse (EMP) testing, large-scale bounded-wave simulators have been constructed for the purpose of illuminating systems by a fast-rising, large-amplitude transient E-field. Although the behavior of the E and H fields in the working volume of most such simulators is very well understood, little attention has been paid to the field levels outside the simulator at distances of several kilometers. The behavior of the fields at these distances depend not only on the details of the simulator structure and its pulser source, but also on the nature of the lossy ground terrain over which the fields propagate.

One example of such a concern is the E and H field environment produced by the Advanced Research EMP Simulator (ARES). Under the auspices of the Defense Nuclear Agency (DNA), this paper investigates an approximate model and presents its estimated EM fields on the ground and in the air at locations away from the simulator. These estimates compare favorably with preliminary peak field measurements on the ground. Further measurements in the air are currently being planned.

The model calculates the radiated fields from the simulator by first determining its current. This is done by modeling the parallel-plate ARES simulator as a two-conductor transmission line structure, and using TEM transmission line theory. Then the expressions developed by Norton for the fields of elementary vertical and horizontal electric dipoles over the lossy earth can be used as a Green's function to determine the E and H fields at distant points. As this formulation is in the frequency domain, numerical fast Fourier transform (FFT) methods are used to obtain the transient responses. This paper describes the details of the analysis and compares calculated fields on the ground with measured data. Accuracies on the order of 30% are noted in many of the data comparisons. In addition, fields at observation locations in the air away from the earth, including peak field contours, have been calculated, and the relative importance of the Norton surface wave in the overall solution is delineated.

TIME-DOMAIN INCIDENT-FIELD EXTRAPOLATION

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Most NEMP simulators do not reproduce the expected NEMP threat. They fail to reproduce both the waveform and the peak field strength of the perceived threat level. This is especially true for radiating and hybrid simulators, which produce a waveform that is significantly different from the waveform of the perceived threat. To compensate for these shortcomings, the measured responses in NEMP assessments have to be corrected (extrapolated) to calculate the response that would be expected from a NEMP.

In this presentation, what is known as incident-field extrapolation will be addressed. This type of extrapolation not only corrects for the difference in waveform, but also tries to correct the different spatial behaviour of the incident field of the simulator compared with the criterion environment. An extrapolation function that is an average over the space of interest, i.e., the simulator test volume, is therefore constructed.

The incident-field extrapolation method that will be presented performs the extrapolation directly in the time domain (see also J.J.A. Klaasen, *Defence Research Establishment Ottawa (DREO) report no. 1076*, May 1991). This method is based on a time-domain extrapolation function which is obtained from the Singularity Expansion Method representation of the measured incident field of the NEMP simulator.

Once the time-domain extrapolation function has been determined, the responses recorded during an assessment can be extrapolated simply by convolving them with the time-domain extrapolation function.

It is found that to obtain useful extrapolated responses, the incident-field measurement needs to be made minimum phase; otherwise unbounded results can be obtained.

Results obtained with this technique are presented, using experimental data.

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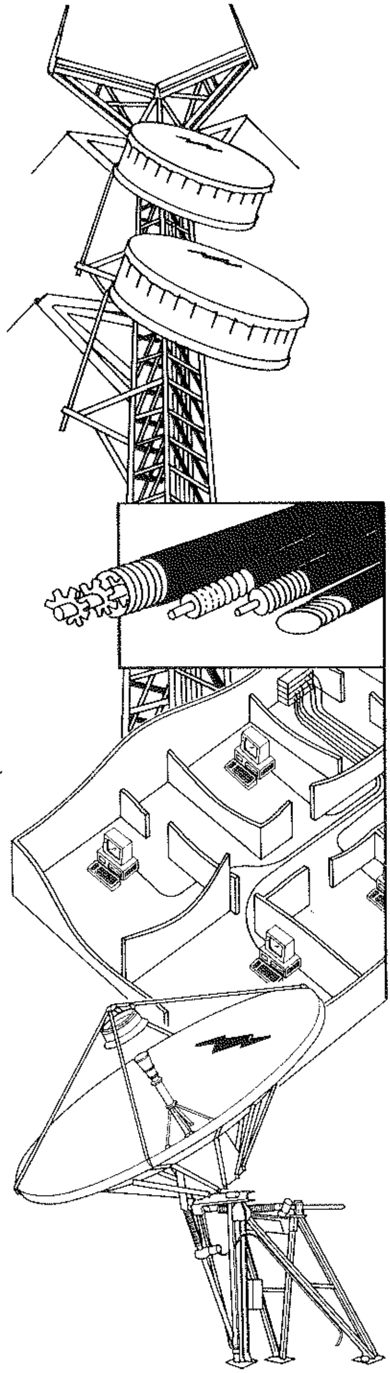

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