NEM 1988

SIXTH NEM SYMPOSIUM
MAY 16-19, 1988

ELECTROMAGNETIC SCIENCES
LABORATORY
SRI INTERNATIONAL
MENLO PARK, CALIFORNIA

SPONSORED BY THE PERMANENT NEM COMMITTEE

CONFERENCE SCHEDULE

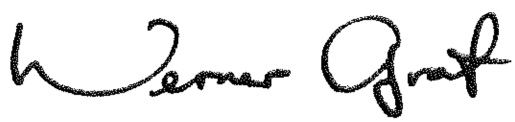
Date	Time	Place	Session	Page
16 May	8:30	Bldg. I, Auditorium	1A – Interaction: Long Lines	1
16 May	8:30	Bldg. A, Room B	1B – Sensors and Instrumentation: Measurement, Recording, and Data Processing Systems I	11
16 May	8:30	Bldg. I, Room S109	1C – Simulation I	23
16 May	8:30	Bldg. I, Auditorium	2A – Interaction: Multiconductor Lines	35
16 May	1:30	Bldg. A, Room B	2B-1 – Sensors and Instrumentation: Measurement, Recording, and Data Processing Systems II	45
16 May	1:30	Bldg. A, Auditorium	2C – Simulation II	55
17 May	8:30	Bldg. I, Auditorium	3A – Assessment: Techniques	65
17 May	8:30	Bldg. A, Room B	3B – Interaction: Cable Shields and Connectors	77
17 May	8:30	Bldg. I, Room S109	3C – Sensors and Instrumentation: Aperture Leakage Measurement Systems	87
17 May	1:30	Bldg. I, Auditorium	4A – (URSI E-1) Environments	95
17 May	1:30	Bldg. A, Room B	4B – Interaction: Apertures	105
17 May	1:30	Bldg. I, Room S109	4C – (URSI E-2) Hardening Technology: Specifications and Standards	115
18 May	8:30	Bldg. I, Auditorium	P1 – Plenary Session	127
18 May	1:30	Bldg. I, Auditorium	6A – Assessment: Assessment of Real Systems	133
18 May	1:30	Bldg. A, Room B	6B-1 – Interaction: Line Penetrations	143
18 May	1:30	Bldg. I, Room S109	6C – (USRI E-3) Hardening Technology: Military and Civilian Specifications and Standards	153
19 May	8:30	Bldg. I, Auditorium	7A – Assessment: EMP Assessment in Power Plants	159
19 May	8:30	Bldg. A, Room B	7B-1 – Hardening Technology: Upset and Damage	167
19 May	8:30	Bldg. I, Room S109	7C – Interaction: EM Coupling II	177

An index to principal authors is on the last page of this program.

Welcome!

As conference chairman, I would like to welcome you to the sixth Nuclear Electromagnetic Pulse Meeting. All of us at SRI are pleased to host our colleagues from the international EMP community, and we hope that your visit is pleasant and productive.

Early May in the San Francisco Bay Area is an exceptionally pretty time. The grass on the hills has not yet ripened, there is snow in the Sierra, and the beaches and redwoods are magnificent. We hope you are able to take in some of these attractions before returning home. Enjoy your stay, and please let us know if we can assist you with NEM matters or with plans for visits after the conference.



Werner Graf

SIXTH BIENNIAL NUCLEAR ELECTROMAGNETIC PULSE MEETING

COMMITTEES

Werner Graf, Chairman

Arrangements: Jeffrey Casper, Chairman
David Rutt, Treasurer
Ted Swift, Publications
David Dana and Leslie Pryne, Conference Record
Cora Taylor, Registration
Carl Baum, Corresponding Secretary

Technical Program: Kendall Casey, Chairman
Hriar Cabayan
Christopher Jones
David Giri
Kelvin Lee

Awards Committee Chairman:
Marvin Morris

Abschirmungszerstörungserdungsdraht (AZED) Award Selection Co-chairmen:
Werner Graf and Manuel Wik

EMP Fellows Selection Committee Co-chairmen:
Edward Vance and William Karzas

This conference is sponsored by the Summa Foundation and is held in cooperation with IEEE organizations (Antennas and Propagation Society, Electromagnetic Compatibility Society, and Power Engineering Society), U.S. National Committee of the International Union of Radio Science (USNC-URSI) Commission B (Fields and Waves) and Commission E (Noise and Interference Environment), Electromagnetics Society, Air Force Office of Scientific Research, Air Force Weapons Laboratory, Army Research Office, Defense Nuclear Agency, Harry Diamond Laboratories, Naval Surface Warfare Center, and the Office of Naval Research.

In addition to the technical program outlined starting on page 1, the following events are planned. Check at the registration desk for details and any changes.

BUSINESS MEETING

The Permanent NEM Committee Luncheon will be Thursday, 19 May, at the Stanford Park Hotel.

SOCIAL EVENTS

Registration Reception, Sunday, 15 May, 6:00-10:00 P.M. at the Holiday Inn, Palo Alto. This is an informal reception during registration to renew old acquaintances and meet new members of the EMP community. Complementary refreshments will be provided.

A Reception for international attendees will be held Monday evening, 16 May, at 6:30 P.M. at the Stanford Park Hotel, Menlo Park.

Awards Banquet, Wednesday, 18 May, at the Holiday Inn. Cocktails will be served at 6:30-7:30 P.M., and the banquet begins at 7:30 P.M. This is the traditional banquet, bringing together all symposium participants for an evening of dining, camaraderie, entertainment, toasts, and awards. Dr. William Graham, Scientific Advisor to President Reagan, will give the banquet address.

TECHNICAL TOURS

Stanford Linear Accelerator Center. SLAC is a research facility that enables international scientists to participate in high-energy physics research programs. The facility includes a two-mile (3.2 km) linear accelerator and is operated by Stanford University for the U.S. Department of Energy.

NASA Ames Research Center. NASA Ames is an aerospace laboratory housing 17 wind tunnels and 5 flight simulators. The two-mile (3.2 km) walking tour includes the observation of research aircraft (including the ER-1) used in high-altitude atmospheric research.

THE AZED AWARD

One of the most serious violations of an electromagnetic shield is the practice by which an unprotected wire is allowed to penetrate a shield surface. A common example of this is a ground wire brought inside a shielded enclosure. The acronym AZED has been created to describe such a "shield destroying wire" (in German: Abschirmungszerstörungserdungsdraht).

An award will be given at NEM 88 for the best example of an AZED. You may qualify for this special award by following the simple contest rules below.

You may submit more than one entry. However, each must be submitted separately. Only registered participants are eligible. A prize of $100.00 will be awarded by the Summa Foundation. The rules are as follows:

1. Find an installation of an industrial or military system that includes protection against EMP, lightning, or other broadband transients.
2. Identify the shield topology and any unprotected penetrating wires that violate the shield topology. (Hint: a common violator is a ground wire brought inside a shielded enclosure.)
3. Obtain a picture or accurate drawing of the shield-destroying wire.
4. Write a brief description of the facility and its location, as well as your name and affiliation, on a separate piece of paper and place it in a sealed envelope.
5. Write a code word on the outside of the envelope. Write the same code word on the back of the picture together with any other descriptive information. Place both in another envelope marked on the outside "AZED AWARD," and submit it at the NEM registration table. All submissions must be received by 5:00 P.M., Tuesday, 17 May. Early submissions can be sent to:

   AZED Award, c/o Werner Graf, MS 404-96
   SRI International, 333 Ravenswood Avenue
   Menlo Park, CA 94025
6. The best entry will receive the AZED AWARD (presented at the banquet). "Best" will be as decided by a panel of judges, whose decision will be final.

SESSION 1A
INTERACTION: LONG LINES

Chairman: J. Norgard, University of Colorado, Colorado Springs
Monday, 16 May (morning) Building I, Auditorium

1 8:30 **Development of a New High-Altitude Electromagnetic Pulse (HEMP) Environment and Resulting Overhead Line Responses,** F. M. Tesche, LuTech, Inc., Dallas, TX; P. R. Barnes Oak Ridge National Laboratory, Oak Ridge, TN

2 8:50 **The Effect of Secondary Scattering on the Induced Current in a Long Wire Over an Imperfect Ground from an Incident EMP,** H. Neff

3 9:10 **Pulse Propagation on a Long Wire in Corona,** J. L. Higginson, MITRE Corporation, Bedford, MA

4 9:30 **Prediction of EMP Simulator Coupling to Power Lines,** D. E. Thomas and F. S. Nickel, The BDM Corporation, Albuquerque, NM

5 9:50 **The Coupling of Intermediate-Time Waveforms to Above Ground Lines,** W. A. Radasky, K. S. Smith, C. W. Jones, and M. A. Messier, Metatech Corporation, Goleta, CA

10:10 Coffee Break

6 10:40 **Successive Approximation Techniques for Analysis of Insulated Wires in Conducting Media,** J. W. Williams and G. D. Rensner, SAIC, Albuquerque, NM

7 11:00 **EMP Coupling to Bent Transmission Lines,** J. A. Cameron, MITRE Corporation, Bedford, MA

DEVELOPMENT OF A NEW HIGH ALTITUDE ELECTROMAGNETIC PULSE (HEMP) ENVIRONMENT AND RESULTING OVERHEAD LINE RESPONSES

F.M. Tesche
LuTech, Inc.
P.O. Box 796012
Dallas, TX 75252

P.R. Barnes
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, TN 37830-6366

Being able to accurately determine the response of an electrical system which is excited by a high altitude nuclear electromagnetic pulse (EMP) requires a knowledge of the time history of the incident EMP field strength, as well as its angle of incidence and polarization. A commonly used, unclassified, description of this environment is provided by the "Bell Laboratory waveform". Recent studies have shown, however, that this EMP waveform tends to over estimate the response of an above-ground transmission line by more than an order of magnitude. As a result, other unclassified high altitude EMP environments have been developed.

This paper discusses the development of two alternate unclassified EMP environment descriptions: one arising from a simple radiating dipole moment model, and the other resulting from curve-fitting the calculated fields from a computer code named CHAP. For both of these EMP models, the electric field at two earth observation points are compared. These fields are then coupled to an above-ground line and the resulting open-circuit voltage responses are compared. Using the CHAP EMP environment, a limited parametric study of the peak positive and negative open-circuit line voltage is then performed and surface plots of these peak voltages are presented.

THE EFFECT OF SECONDARY SCATTERING
ON THE INDUCED CURRENT IN A LONG WIRE
OVER AN IMPERFECT GROUND FROM AN INCIDENT EMP

Herbert Neff

Abstract

The effect of secondary scattering that is produced by the induced current in an infinitely long and finitely conducting wire over a plane and finitely conducting earth from an incident electromagnetic pulse is investigated. This is accomplished by finding the field of a Hertzian dipole over the earth and identifying that part which is secondary scattering. Frequency-domain results for the overall induced current require that certain infinite integrals be numerically evaluated. Fourier inversion to the time domain in turn requires the numerical evaluation of another infinite integral. When the results are compared to those where secondary scattering is ignored, it is found that secondary scattering slightly increases the current for the case of broadside incidence, and secondary scattering reduces the current for the case of grazing incidence by as much as two orders of magnitude in some cases. Peak currents are much smaller than previously thought. These general results hold for all of the earth parameters that were used in this study.

PULSE PROPAGATION ON A LONG WIRE IN CORONA

Jeffrey L. Higginson

The MITRE Corporation
Burlington Road
Bedford, Massachusetts 01730

Past theoretical studies performed at MITRE indicated that a pulse traveling on a wire enveloped in corona might experience amplitude attenuation and propagation velocity changes. To confirm these predictions, we conducted a series of experiments involving pulse propagation on a wire in corona.

Laboratory tests were performed on a wire, coaxial to a larger cylinder, fully enveloped in uniform static corona. Wires of three different diameters (2, 10, and 20 mils) were tested. The level of static corona, measured as corona current, was varied from 1 to 250 μA/m. With corona present, a series of fast rise-time pulses were injected onto the wire, and observed with a Tektronix CT-1 current probe and 7912 digitizer. Current pulses as small as 100 mA and as large as 80 A were employed.

Our observations suggest the presence of a pulsed current threshold below which no effects on a pulse are observed. Above this threshold, however, pulse attenuation and distortion is apparent. The data shows that the threshold varies in a nonlinear fashion with wire diameter. Thresholds of 0.4 A for a 2-mil wire, 1.5 A for a 10-mil wire, and 1.7 A for a 20-mil wire were measured. Observations suggest that the pulse current threshold is not a strong function of the background corona, and is much more dependent on the polarity of the corona. Additional experiments measured the changes to a current pulse in varying levels of background corona; representative data from these measurements is presented.

PREDICTION OF EMP SIMULATOR COUPLING TO POWER LINES

D.E. Thomas and F. S. Nickel
The BDM Corporation
1801 Randolph Road SE
Albuquerque, NM 87106

This paper deals with predicting electromagnetic interference (EMI) effects which may result from the operation of an electromagnetic pulse (EMP) simulator. The situation analyzed involves a horizontally-polarized dipole (HPD) facility, which is positioned inside a mile-wide square loop of 12.5 kV distribution lines; in addition, 69 kV lines are run along two sides of the loop. The HPD simulator is about a quarter of a mile from the 12.5 kV lines at closest approach.

The CASSANDRA program was used to predict coupled current and voltage transients at selected points along both 12.5 and 69 kV systems. CASSANDRA is an admittance-based transmission line program, and takes into account the pulse shape, magnitude, and polarization of the simulated EMP; the conductivity and permittivity of the soil in the area; and, length, height, and relative positions of both the power line network and the simulator. The power line network itself was subdivided into several dozen small sections, in order that the angle of arrival of the simulated EMP could be calculated independently for each small section. Thus, CASSANDRA can be used for "near-field" problems, in which the incident electromagnetic fields vary widely with position on the excited structure (power distribution network); this capability provides smaller, more realistic estimates of induced power-line voltages and currents than would an approach based on infinitely flat TEM waves coming from a single point in space.

This work was sponsored by the Boeing Military Aircraft Company.

The Coupling Of Intermediate-Time Waveforms To Above Ground Lines*

by

William A. Radasky
Kenneth S. Smith
Christopher W. Jones
Michael A. Messier

Metatech Corporation
358 S. Fairview Avenue, Suite E
Goleta, CA 93117

Although the coupling of early-time (t<1μs) HEMP waveforms to long lines has been discussed in the literature for many years, there has recently been substantial interest in whether the HEMP fields at later times (t>1μs) contribute to the long line coupling.

This paper examines several hypothetical intermediate-time incident HEMP waveforms and considers methods for treating earth reflections and coupling to above ground lines. The coupling cases presented include variations in ground conductivity, angle of incidence and line loads.

*Research performed under SRI C-11617, DNA001-86-C-0143.

SUCCESSIVE APPROXIMATION TECHNIQUES FOR ANALYSIS OF INSULATED WIRES IN CONDUCTING MEDIA

John W. Williams and Gary D. Rensner
Science Applications International Corp.
2109 Air Park Rd, SE
Albuquerque, NM 87106
505-247-8787

Solution of the electromagnetic boundary value problem for a cylinder immersed in various media is a subject of theoretical and practical interest. Early work by Sommerfeld yielded successive approximation solutions for the principal wave on a solid cylinder in a dielectric medium (J.A. Stratton, Electromagnetic Theory, McGraw-Hill Book Co., 1941, pp.524-537). Approximate solutions for the coaxial case were estimated under the assumption that the outer medium is an ideal or nearly-ideal conductor (Stratton, loc. cit., pp. 545-554). Based upon the early use of successive approximations for a bare cylinder in a dielectric medium, attempts were made to adapt the formalism to an insulated wire in a poorly conducting medium (D.R. Marston and D.R. Graham, EMP Interaction Note 24, 1966, and J.R. Hill and M.R. Wilson, MRC Report AMRC-N-5, 1973).

In this paper we will present a successive approximation technique directly applicable to the three-media problem of an insulated cylinder surrounded by a conducting medium. This formalism is an extension of the original approach developed by Sommerfeld. The technique is applied to the calculation of transmission line parameters for an insulated wire in soil. Results obtained with frequency-dependent constitutive parameters are compared with those calculated with constant soil conductivity and dielectric constant. It is shown that the successive approximation technique converges rapidly and is reasonably independent of the initial approximation.

J. A. Cameron
The MITRE Corporation*
Mail Stop R245
Burlington Road
Bedford, Massachusetts 01730

EMP COUPLING TO BENT TRANSMISSION LINES

This paper presents an extension of the distributed source transmission line model that calculates the EMP response of a bent transmission line. Although presented for an overhead transmission line, the method is also applicable to buried lines.

The standard method for calculating EMP coupling to an overhead transmission line assumes a straight, semi-infinite line (1). We converted the integral over a straight, semi-infinite line to a sum of integrals, with each integration along a straight line segment. The component of the electric field parallel to the wire was calculated separately for each segment. This calculation involved two steps. First, a coordinate transformation was applied to find the angle of incidence of the line segment (e.g., with the z axis along the line). Next, a phase correction was applied, since the standard theory implicitly assumes that the line is straight when calculating the phase of the frequency domain electric field.

The open circuit voltage waveform of a bent transmission line was found to be substantially different from that of a semi-infinite line. The nature of the difference depends strongly on the exact geometry of the transmission line. In many cases, the bent line was found to receive significantly less total energy than a semi-infinite line.

(1) E. F. Vance, Coupling to Shielded Cables, New York: Wiley 1978.

*This work was supported by the U.S. Air Force, Contract F19628-86-C-0001.

SESSION 1B
SENSORS AND INSTRUMENTATION: MEASUREMENT, RECORDING, AND DATA PROCESSING SYSTEMS I

Chairman: J. Shiloh, Rafael, Haifa, Israel

Monday, 16 May (morning) Building A, Conference Room B

1 8:30 **The Modular Data System (MDS),** B. Burton, Kaman Sciences Corp., Dikewood Div., Santa Monica, CA; Lt. R. MacRall, AFWL, NM

2 8:50 **Characterization of the HDL CW Measurement System,** Y. Rosenberg, ENESCO, Inc., Springfield, VA; L. Rose, MRC, Colorado Springs, CO; W. Scott and J. Brackett, HDL, Adelphi, MD

3 9:10 **Use of Modern Network Analyzers in Making Simulated EMP Measurements,** S. Kashyap, Defence Research Establishment and S. R. Mishra, National Research Council, Ottawa, Ontario, Canada

4 9:30 **Data Acquisition and Processing with a Mobile EMI / EMP Measurement System,** F. S. Nickel and C. M. Wiggins, BDM Corporation, Albuquerque, NM

5 9:50 **μDAS and TSA - Systems for Acquiring and Processing Transient Measurements,** D. G. Baur and T. J. Kearns, BDM Corporation; Maj. C. G. Mumford, III and Lt. T. A. Hoang, AFWL, NM

10:10 Coffee Break

6 10:40 **Development and Testing of Extremely Fast Electromagnetic Pulse Instrumentation,** G. D. Sower, EG&G Washington Analytical Services Center, Inc., Albuquerque, NM

7 11:00 **Nanosecond Pulser Risetimes as Measured by a Portable Screenbox Waveform Capture System,** W. T. Clark, III, The BDM Corporation, Albuquerque, NM; R. V. Saxton, BDM Management Services, Kirtland AFB, NM

8 11:20 **Analysis of EMP Measurement System Performance,** M. Dion and S. Kashyap, Defence Research Establishment, Ottawa, Ontario Canada

9 11:40 **End-To-End Data System Functional Characterization,** J. J. Podlesny, TRW, Albuquerque, NM

THE MODULAR DATA SYSTEM (MDS)

Bruce B. Burton
Kaman Sciences Corporation
Dikewood Division
2800 28th Street, Suite 370
Santa Monica, Ca 90405

Lt. Ron MacRall
Air Force Weapons Laboratory/NTAAT
Kirtland AFB, NM 87117-6008

A high performance EMP data acquisition system for both transient and continuous wave (CW) testing has been designed, built and fielded on the EMP Test Aircraft (EMPTAC).

The system typically consists of eight parallel transient or two parallel CW recording channels. Fiber optic (FO) transmitters for each channel with up to 10 input ports are located on the test object. These fiber optic transmitters contain signal conditioning to measure signal levels varying from approximately 12 microvolts to 1.4 kilovolts for transients (200 MHz bandwidth) or from 1.3 x 10^{-18} watts to 1 watt for CW signals (100 Hz bandwidth). The FO transmitter includes high and low pass filters to improve the signal to noise ratio (SNR) of transient recorded signals for input spectrums that are biased towards one frequency range. A single mode 1300 nm fiber optic link sends the amplitude modulated response signal from the test object to its receiver up to a few km away. Signal conditioning in the receiver allows one to use the fiber optic link at a wide range of optical modulation depths to trade off SNR and THD.(total harmonic distortion) The receiver provides either manual or programmatic control via the General Purpose Interface Bus (GPIB). The control electronics have built in self checks for all the signal conditioning state changes. The receiver is a two slot Computer Automated Measurement and Control (CAMAC) module designed to be space efficient with an adjacent 1.348 G sample/s LeCroy transient recorder.

A 10 x 2 RF switch matrix allows one to programmatically use a spectrum analyzer and oscilloscope to look at the built in noise and Time Domain Reflectometer (TDR) sources, located in the front end of the fiber optic transmitter. System bandwidth from the probe to the recorders is typically 2 kHz to 600 MHz with a smooth and stable response up to at least 1.3 GHz. This allows extended frequency response measurements using signal compensation but with less SNR. For large input signals the fiber optic link SNR (RMS signal to RMS noise) is observed between 30 dB and 50 dB (variances between parallel channels) over a 200 MHz bandwidth, while the THD is less than 1 percent. The discussion includes a comparison of: fiber optic link sources (Light Emitting Diode vs. LASER diode), PIN (P-type Intrinsic N-type) diode vs. APD (Avalanche Photo Diode) receivers, single mode vs. multimode fiber, as well as recommendations to further improve the FO link SNR.

Characterization of the HDL CW Measurement System

Yuri Rosenberg, ENSCO, Inc
5400 Port Royal Road, Springfield, VA 22151-2388

Larry Rose, Mission Research Corporation
4935 North 30th Street, Colorado Springs, CO 80919

Walter Scott, Harry Diamond Laboratories
Jim Brackett, Harry Diamond Laboratories
2800 Powder Mill Road, Adelphi, MD 20783-1197

The HDL CW Measurement System, located at the Woodbridge Research Facility in Woodbridge, VA., is a newly installed system and was developed primarily for studying EMP effects on Mobile Ground Based C^3I ($MGBC^3I$) equipment. The system consists of the EM field generating and data collecting/processing equipment.

This report discusses the data acquisition system and the physical and electromagnetic properties of the system. Field mapping data and responses of simple antenna structures which were measured during the recent system Calibration Test are presented. The quality of the radiated field (in terms of planarity, uniformity, and repeatability) will be discussed quantitatively. A review of CW test techniques and lessons learned from the recent test efforts will be discussed.

This effort was sponsored by Harry Diamond Laboratories under contract DAAL02-86-D-0043.

Use of Modern Network Analyzers In Making Simulated EMP Measurements

S. Kashyap*
Electronics Division
Defence Research Establishment
Ottawa, Ontario, Canada
K1A 0Z4
(613) 998-2250

S.R. Mishra
Electrical Engineering Division
National Research Council
Ottawa, Ontario, Canada
K1A 0R8
(613) 993-9074

ABSTRACT

This paper concerns the use of a modern network analyzer with time domain option for making EMP measurements. Results of simulated EMP responses of various antennas including those on scale models of a car and a helicopter are presented.

SUMMARY

Traditional network analyzers allow the measurement of transfer and/or impedance function through frequency domain sinusoidal wave testing. Some modern versions also have the capability of displaying the time domain response of a network by computing the inverse Fourier transform of the frequency domain response. The time domain response shows the reflection coeficient vs time yielding the magnitude and location of each discontinuity of the network. Transmission coefficient vs time can also be displayed and gives the simulated transient response of the network. This paper describes the use of a desk-top computer controller and a network analyzer with a time domain option for obtaining the transient EMP response of a network.

Our measurement instrumentation consists of an HP-8510 (45 MHz-18GHz) or HP-8753A (300kHz-3GHz) network analyzer. A desk-top computer controller (HP-9836) is used for data acquisition and communicates with the network analyzer over the IEEE-488 bus. Input impedance measurements were made for a number of antennas including a monopole, an antenna on a 1:7 model car, and an antenna on a 1:24 model helicopter. The measurements are first made in the frequency domain. The frequency must be scaled upward by the appropriate scale factor in these measurements. The HP-9836 is used to weight the frequency domain response with the EMP function and the network analyzer then computes and displays the transient EMP response of the antenna. Alternatively, the HP-9836 is used for computing the inverse Fourier transforms and displaying the time domain EMP transient response.

The results of our measurements on a number of antennas will be presented in both frequency and time domains. The effect of various factors such as the length of an antenna, bends in the antenna, the antenna base structure, the number of measurement points in the frequency range of interest, etc. will be discussed in detail.

* NRC Senior Research Officer located temporarily at DND

DATA ACQUISITION AND PROCESSING
WITH A
MOBILE EMI/EMP MEASUREMENT SYSTEM

F.S. Nickel and C. M. Wiggins
The BDM Corporation
1801 Randolph Road, S.E.
Albuquerque, NM 87106

A mobile EMI measurement and data processing system capable of acquiring both radiated and conducted "long time domain" transients will be described. This system has proven to be in high voltage substation environments and can additionally be utilized in a broad range of measurement situations including EMC and EMP.

This paper focuses on some of the problems encountered as well as the measurement and processing techniques that can be applied when using the system to investigate the type of transients associated with the operation of high voltage switchgear. Several methods of acquiring and processing large (one Megabyte) data records will be demonstrated and compared for useability in the EMI/EMP field. Instrumentation correction algorithms will be discussed for field and direct coupled current measurements.

This work is sponsored by the Electric Power Research Institute (EPRI) of Palo Alto, California.

DAVID G. BAUR
BDM CORPORATION and
THOMAS J. KEARNS
ALBUQUERQUE, NEW MEXICO

MAJ. CAREY G. MUMFORD III and
LT. TUAN A. HOANG
AFWL/NTAOT
KIRTLAND AFB, NEW MEXICO

uDAS and TSA – Systems For Acquiring and Processing Transient Measurements

Abstract

Advances in computer and digitizer technologies have presented the opportunities for improved computer control, digitization and processing of transient data. An integrated data acquisition and processing system was developed at the AFWL EMP test facilities. The uDAS package provides the capability to control a system from a VAX/VMS-based machine (E.G., MicroVAX/VMS) and provides for the interactive control of the data acquisition process. The TSA package provides improved performance, flexibility, and capabilities over previous signal processing systems, and is adaptable to the changing data requirements such as increased bandwidth or dynamic range.

The acquisition system was designed to satisfy the present and future needs in control of digitizers and "other" elements. Initially setup for operation with Nanofast fiber optic links and LeCroy 6880 digitizers, add ons will include LeCroy TR8828C and "Lightning" digitizers to enhance the system bandwidth. The original design architecture and interface to processing systems have ensured that present and future requirements for greater bandwidth and dynamic range ($\geq$ 1 GHz and $\geq$ 60 dB) are readily satisfied.

The uDAS system has operational characteristics that support EM testing ranging from low frequency (KHz type) to relatively high frequency (GHz type) transients. The system was initially setup to attempt 20 measurements per channel per hour (3 minute turnaround) and normal operations are anticipated to be in the 5 minute turnaround time range with at least 4 measurements "accepted" per channel per hour. After acceptance of a waveform, the data is automatically shipped for data processing and hardcopy production on a noninterference basis with the data acquisition activities.

The primary issues which drove the development of the TSA data processing package were the result of new data requirements in both technical and operational areas. The requirements for real time processing of data from low bandwidth, long record length digitizers (such as the LeCroy TR8828C) through high bandwidth, short record length digitizers (such as the "Lightning"), and the recombining in the time and/or the frequency domains necessitated both new software routines and a more flexible system than was available. The TSA package was designed to satisfy these needs and process data in interactive and batch modes.

To fulfill these requirements TSA had to be easily expandable, flexible as an interactive tool, and robust enough to process varying transient data in a batch mode. To add commands, the Digital Equipment Corporation Command Languauge Interpreter (CLI) is used. Using this utility, a new routine can be added to TSA by writing an interface between TSA's internal data structures and the routine, and adding an appropriate command verb to the CLI tables. Since TSA's expression evaluator provides access to all the transient data in a waveform as well as the Fortran mathematical functions, TSA's command procedures can be used as a programming language. Once developed, TSA command procedures can be used in a batch mode to process larger quantities of data for verifcation of the new algorithm. In addition to algorithm development, command procedures are the basis for batch processing of all acquired data.

The presentation will discuss the architecture and configuration of the software and projected hardware elements that are appropriate for transient measurements and representative commands and processing steps that are available.

DEVELOPMENT AND TESTING OF EXTREMELY FAST ELECTROMAGNETIC PULSE INSTRUMENTATION

G.D. Sower

EG&G Washington Analytical Services Center, Inc.
P.O. Box 9100
Albuquerque, NM 87119
Telephone No. (505) 243-2233

ABSTRACT

The state-of-the-art of fast transient data acquisition systems for electromagnetic signals is ever changing in response to new requirements. Measurements with rise times of less than 100 picoseconds are possible using sampling techniques, faster rise times are desirable.

The instrumentation described herein includes the electromagnetic transducers (sensors), signal conductors, signal conditioning, and waveform recording. Each component in the system has its own characteristic rise time, which contributes to the total system rise time. Everypart of the system must therefore be optimized in order to minimize the system rise time. For example, even moderate lengths of coaxial cable can cause significant degradation of fast transient signals.

In certain applications, meaningful data can be obtained for bandwidths exceeding that of the instrumentation system. This is accomplished by numerical processing using "deconvolution" techniques, wherein the instrumentation system transfer function is removed from the recorded data. A factor of about two improvement in rise time measurement capability is possible with this technique, but is not always realizable due to random noise reocrded with the data.

Nanosecond Pulser Risetimes As Measured By A Portable Screenbox Waveform Capture System

W.T. Clark III
The BDM Corporation
1801 Randolph Road, SE
Albuquerque, New Mexico 87106

R.V. Saxton
BDM Management Services Company
Simulation Test Facilities Division
P.O. Box 5412
Kirtland AFB, New Mexico 87185

Abstract

The objectives of this effort were to determine if a portable screenbox system was capable of capturing the nanosecond risetimes of the RES/HAG-1A pulser and determine the differences in risetimes between the pulser alone and the pulser with its antenna array. Experiments were conducted at the Horizontal Polarized Dipole facility located on Kirtland AFB, New Mexico. Our method was to place a personal computer and a Tektronix 7104 oscilloscope (bandwidth of 1 GHz) equiped with a digitizing (charge coupled device) camera in a screenbox. Signal was introduced using a variety of conventional probes while power was provided via a filtered land line. Waveforms were written on the scope, captured by the camera, then initially calibrated, stored and displayed by the computer. This system was not dependent on a fiber optic signal transmitting system, with its inherent bandwidth limitations, to a remote acquisition station. The system successfully acquired the initial nanoseconds of the pulse and automatically digitized the signal, was portable and required a single operator. Further data reduction and analysis, including folding out the probes and signal integration, was conducted in the conventional manner on a MicroVAX computer using Transient Signal Analysis. Data were acquired at various time base settings down to 500 ps/division, depicting risetimes in the 1.2 ns range. Substantiating data were acquired using a Tektronix 7250 oscilloscope (bandwidth of 6 GHz) in a screenbox. Future development involves adding a LeCroy 6880 to the screenbox, thereby enabling capture of the entire waveform as well as the first few nanoseconds. This will allow a single operator to conduct high resolution total waveform data acquisition without a dependence on other personal or interfering with higher priority requirements.

Analysis of EMP Measurement System Performance

M. Dion
Electronics Division
Defence Research Establishment
Ottawa, Ontario Canada
K1A 0Z4
(613) 998-2611

S. Kashyap
Electronics Division
Defence Research Establishment
Ottawa, Ontario, Canada
K1A 0Z4
(613) 998-2250

ABSTRACT

Recording of an electromagnetic pulse generated by a nuclear weapon requires specialized equipment with unique capabilities. It may also need restructuring of the incident field or current from the recorded data. This paper concerns the analyses of the effects of various signal conditioning devices on system performance.

Most field sensors and some current sensors used in EMP measurements produce a time derivative of the field or current being measured. Since the desired quantity is the actual field or current, an integration is required. The integration may be performed using hardware or software or a combination of the two. Amplification, digitization and restructuring are also commonly involved. There are a number of factors which affect the performance of the whole system. This paper analyses the effects of various parameters including the sensor sensitivity, the sensor bandwidth, the integrator time constant, the amplifier bandwidth, the digitizer bandwidth and the digitizer sampling rate. A code for prediciting the performance of the system using the parameters involved is developed. Several options for improving the performance of the system are discussed and the results of implementing them are presented. The results of both numerical and analytical computations in the frequency as well as time domains are given.

END-TO-END DATA SYSTEM FUNCTIONAL CHARACTERIZATION

John J. Podlesny

TRW
Albuquerque Engineering Office
2340 Alamo SE
Albuquerque, NM

A typical EMP data channel has many individual items from sensors to data links to recorders to software processing. These data systems are constantly upgraded to take advantage of new hardware and software modifications. Some of these upgrades may take place during a test program. We have developed a method to evaluate an EMP data acquisition channel which can reduce the impact on a test program in progress. The concept is directed at two main areas: data channel functional checking and trouble shooting assistance. This presentation shows how to verify that both the hardware and software are functioning correctly to within certain criteria. The methodology does not replace calibration, but adds a functional check of the installed data channel which greatly increases the confidence that it will work when it is needed.

SESSION 1C

SIMULATION I

Chairman: Maj. C. Schubert, Defense Nuclear Agency

Monday, 16 May (morning) Building I, Room S109

1 8:30 **Lumped Element Networks for Replacing Sections of a Buried Transmission Line**, Y. G. Chen, R. Crumley, and S. Lloyd, Maxwell Laboratories, Inc., San Diego, CA; C. E. Baum, AFWL, Kirtland AFB, NM and D. V. Giri, Pro-Tech, Berkeley, CA

2 8:50 **Design Procedures for Arrays which Approximate a Distributed Source at the Air-Earth Interface**, Y. G. Chen, S. Lloyd and R. Crumley, Maxwell Laboratories, Inc., C. E. Baum, AFWL, Kirtlan AFB, NM, and D. V. Giri, Pro-Tech, Berkeley, CA

3 9:10 **Winding Topology for Transformers**, C. E. Baum, AFWL, NM

4 9:30 **Twin Coaxial Balun (TCB) Development**, G. D. Sower and L. M. Atchley, EG&G WASC, Albuquerque, NM

5 9:50 **Common and Differential TEM Modes for Two Wires Above a Ground Plane,** C. Zuffada, Kaman Sciences Corp., Dikewood, Santa Monica, CA; N. Engheta, The University of Pennsylvania, Philadelphia, PA

10:10 Coffee Break

6 10:40 **Field Characterization of the Hardness Surveillance Simulator (HSI) Working Volume**, C. Zuffada, Kaman Sciences Corporation, Dikewood Division, Santa Monica, CA; T. Smith, AFWL, NM

7 11:00 **Positioning Loops with Parallel Magnetic Dipole Moments to Avoid Mutual Inductance**, J. D. Quinn, Materials Research Laboratory, Melbourne, Australia; C. E. Baum, AFWL, NM

8 11:20 **Networks for Producing Composite Magnetic Dipole Moments from Various Loops**, J. D. Quinn, Materials Research Laboratory, Melbourne, Australia; C. E. Baum, AFWL, NM

9 11:40 **An Equal Time Electromagnetic Lens for a Biconical Antenna**, J. T. Naff and J. E. Faulkner, Physics International Company, San Leandro, CA; G. D. Sower and J. Doran, EG&G, Albuquerque, NM; I. Kohlberg, Kohlberg Associates, Inc., Alexandria, VA

LUMPED ELEMENT NETWORKS FOR REPLACING SECTIONS OF A BURIED TRANMISSION LINE

Y. G. Chen, R. Crumley, and S. Lloyd
Maxwell Laboratories, Inc., San Diego, CA

Carl E. Baum
Air Force Weapons Laboratory

and

D. V. Giri
Pro-Tech, 125 University Avenue, Berkeley, CA 94710

Abstract

There are various techniques to simulate the nuclear EMP, in or near source regions as discussed in [1]. A nuclear EMP near the air-earth interface results in a large distributed electromagnetic source on the interface. Such an electromagnetic source produces an underground field that propagates very nearly perpendicular to the interface. In the context of simulating this underground field, past works have addressed the problem of analyzing a buried transmission line formed by vertical "plates" constructed in practice as arrays of vertical rods in ground. Such a waveguiding structure, when excited by an appropriate low-frequency source is a viable EMP simulation technique for use with underground systems. In the development phase of such a technology, there exists a need to artificially elongate the buried line by using lumped element networks. These networks are attached electrically to the buried end of the vertical plates and in effect, the networks simulate the simulator plates and earth. This paper addresses such a network concept and its design considerations. The actual design, fabrication and testing of an example network is also presented.

---

[1]. C. E. Baum, "EMP Simulators for Various Types of Nuclear EMP Environments: An Interim Categorization," Sensor and Simulation Note 240, January 1978, and Joint special issue on NEMP, IEEE. Trans. on Antennas and Propagation, January 1978, pp. 35-53 and IEEE Trans. on EMC, February 1978, pp. 35-53.

DESIGN PROCEDURES FOR ARRAYS WHICH APPROXIMATE A DISTRIBUTED SOURCE AT THE AIR-EARTH INTERFACE

Y. G. Chen, S. Lloyd and R. Crumley
Maxwell Laboratories, Inc.
8888 Balboa Avenue, San Diego, CA 92123

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

and

D. V. Giri
Pro-Tech, 125 University Avenue, Berkeley, CA 94710

Abstract

This paper addresses a general electromagnetic problem of simulating a distributed source at an interface of a conducting dielectric by an array of pulsers. One possible application lies in the simulation of the distributed source at the air-earth interface caused by a nuclear EMP near the interface [1]. Other electromagnetic applications may include geological prospecting, detection of buried objects and the study of the coupling of the fields generated by natural lightning to undergorund objects. In general, the design procedures of arrays approximating distributed sources considered here are applicable whenever, a need exists for coupling electromagnetic waves into the earth. Appropriate theoretical considerations, as well as design procedures for the arrays will be discussed.

---

[1]. C. E. Baum, "EMP Simulators for Various Types of Nuclear EMP Environments: An Interim Categorization," Sensor and Simulation Note 240, January 1978, and Joint special issue on NEMP, IEEE Trans. on Antennas and Propagation January 1978, pp. 35-53 and IEEE Trans. on EMC, February 1978, pp. 35-53.

WINDING TOPOLOGY FOR TRANSFORMERS

C. E. Baum
Air Force Weapons Laboratory
Kirtland AFB
Albuquerque, New Mexico 87117-6008

In order to improve the high-frequency performance of pulse transformers, one of the problems to be addressed is the reduction of the leakage inductance associated with leakage flux between primary and secondary windings. This note introduces the concept of making such windings out of coaxial (or higher order multiaxial) cables, with the outer shields of primary and secondary windings bonded together, so as to effectively remove this leakage inductance.

TWIN COAXIAL BALUN (TCB) DEVELOPMENT

G.D. Sower
L.M. Atchley

EG&G Washington Analytical Services Center, Inc.
P.O. Box 9100
Albuquerque, NM 87119
Telephone No. (505) 243-2233

ABSTRACT

The Twin Coaxial Balun (TCB) is a transformer which accepts a signal, either pulse or CW, from a 50-ohm power amplifier and converts it to differentially (push-pull) drive a pair of symmetric 100-ohm transmission lines. This note describes the manufacture and response of the TCB-1A, as built to the specifications of AFWL Measurement Note 31.

COMMON AND DIFFERENTIAL TEM MODES FOR TWO WIRES ABOVE A GROUND PLANE

C. Zuffada

Kaman Sciences Corporation, Dikewood Division
Santa Monica, California 90405

N. Engheta

Formerly with Kaman Sciences Corporation, presently with
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, PA 19104-6390

Abstract

The performed analysis presented predicts the field produced by two parallel wires over a perfectly conducting, infinite ground plane. Both common mode and differential mode excitation of the wires are considered. The field uniformity is quantified by calculating the 2-norm and the ∞-norm errors. Impedance calculations are also presented.

Work funded by AFWL, Kirtland AFB, under Contract F29601-84-C-0042, Subtask 04-02. The material to be presented is contained in Sensor and Simulation Note 305, published in July 1987.

FIELD CHARACTERIZATION OF THE HARDNESS SURVEILLANCE SIMULATOR (HSI) WORKING VOLUME

C. Zuffada

Kaman Sciences Corporation
Dikewood Division
2800 28th Street, Suite 370
Santa Monica, California 90405

T. Smith

Air Force Weapons Laboratory
Kirtland Air Force Base
Albuquerque, New Mexico 87117

ABSTRACT

The results of the field mapping of the HSI (also called the Achilles III) in the working volume are discussed for its two modes of operation, common and differential. In the common mode two wires are driven in place against the ground, whereas in the differential mode they are driven against each other. The electromagnetic behavior of the simulator is described in terms of a simple quasi-static model perturbed by the presence of sources of reflections inherent to its physical construction. The selection of the optimum working volume in order to keep the reflections to a minimum is also discussed. It was found that with the proper choice of the working volume the illuminator operates satisfactorily and produces fields which are in agreement with those predicted by a quasi-static transmission line model.

Positioning Loops with Parallel Magnetic Dipole Moments to Avoid Mutual Inductance

J.D. Quinn
Materials Research Laboratory
DSTO Melbourne
PO Box 50 Ascot Vale 3032 Vic Australia

and

C.E. Baum
Air Force Weapons Laboratory
Kirtland AFB NM 87117-6005

ABSTRACT

A scheme is described for arranging a number of circular loops on a spherical surface to produce magnetic dipole moments, while cancelling higher multipole moments. The ability to arrange loops so as to behave as dipoles then gives rise to the possibility of arranging a set of such dipoles in space so that there is zero mutual inductance. The relative location of parallel magnetic dipoles for zero mutual inductance is given by a particular angle between their dipole axes and a line between the dipoles, and so is valid regardless of the radius of magnetic dipoles. An earlier paper investigated the feasibility of adding the magnetic dipole moments of a number of dipole loops to produce an electromagnetic field with magnetic dipole moments covering a wide frequency range. The combined results of the two associated papers indicate that it is possible to construct a log-periodic magnetic dipole array to produce a controllable electromagnetic field for some interaction measurement purposes.

Reference: J.D. Quinn and C.E. Baum, "Networks for Producing Composite Magnetic Dipole Moments from Various Loops" SSN 298

Networks for Producing Composite Magnetic Dipole Moments from Various Loops

J.D. Quinn
Materials Research Laboratory
DSTO Melbourne
PO Box 50 Ascot Vale 3032 Vic Australia

and

C.E. Baum
Air Force Weapons Laboratory
Kirtland AFB NM 87117-6008

ABSTRACT

The possibility of using a series of magnetic dipoles to produce a composite magnetic dipole moment has been established. A concept is proposed of exciting a set of magnetic dipoles, comprising loops with prescribed electrical properties, by means of an electrical network which they form part. A network model is developed for describing such a series of loops that can exhibit desirable efficiency and impedance properties. A cascaded low-pass constant-resistance network in which each stage includes a magnetic dipole is examined and an expression produced for the composite magnetic dipole as a function of its network parameters. This gives rise to the possibility of producing a controllable electromagnetic environment relatable over any frequency range to the network's input current and its electrical properties which in some cases may approximate a transmission line.

AN EQUAL TIME ELECTROMAGNETIC LENS FOR A BICONICAL ANTENNA*

BY

J.T. NAFF,** J.E. FAULKNER,** G.D. SOWER,+ J. DORAN,+ AND I. KOHLBERG++

An equal transit time electromagnetic lens for both conical and biconical antennas (transmission lines) has been developed. The lens provides for the transition of a spherical wave from the dielectric comprising the lens to the dielectric comprising the antenna, thus forming a spherical wavefront. This configuration is defined as an equal time window (ETW) since all rays which leave the apex of the lens arrive at the terminal wavefront at the same time. An ETW is a useful development allowing the highly electrically stressed region of an EMP simulator to be insulated with oil without degrading the quality of the simulation environment, for example.

A computer program has been developed that provides coordinates for the lens shape as a function of bicone impedance and the lens and antenna dielectric constants. The program computes the lens shape via an iterative process.

A theoretical model has been developed which rigorously proves that an ETW can be built. The analytical model has been found to be in excellent agreement with the iterative-numerical techniques. In addition, sensitivity to variations in construction accuracy and deviations in dielectric constant relative to the design value have been examined.

An experimental confirmation of the ETW concept has been successfully completed.

The iterative method and the theoretical model of the ETW will be presented. The results of the experimental test will also be presented.

* Work Sponsored By the Defense Nuclear Agency and the Harry Diamond Laboratories

** Physics International Company, San Leandro, Ca.

+ EG&G, Inc. , Albuquerque, N. M.

++ Kohlberg Associates, Inc., Alexandria, Va.

SESSION 2A
INTERACTION: MULTICONDUCTOR LINES

Chairman: P. Barnes, Oak Ridge National Laboratory, TN
Monday, 16 May (afternoon) Building I, Auditorium

1 1:30 **The Effects of Capacitive and Conductive Coupling in Networks of Transmission Lines,** J. D. Norgard, J. R. Curry and R. M. Sega, MRC, Colorado Springs, CO

2 1:50 **Coupling Phenomena in Multiconductor Screened Telephone Cables,** B. Djebari, A. Zeddam, F. Brunel, and R. Leray, Centre National d'Etudes des Télécommunications, Lannion, France

3 2:10 **Multiconductor Cable Response Dependency on Propagation Modes,** J. Beilfuss, HDL, Adelphi, MD, A. Bell, R. Gray, and R. Hamrick, ENSCO, Inc., Springfield, VA

4 2:30 **Common-Mode Voltage Induced on a Multi-Wire Shielded Cable Illuminated by an Electromagnetic Pulse,** A. Zeddam, Centre National d'Etudes des Télécommunications, Lannion, France; P. Degauque, Université de Lille, France

2:50 Coffee Break

5 3:20 **Inductive and Capacitive Coupling of Transients to Transmission Lines,** F. M. Weitze, J. L. ter Haseborg, A. Jordan, Technical University Hamburg-Harburg, West Germany

6 3:40 **Effects of Risetime on Coupling to Short Cables,** L. Jones and A. Cyganowski, SAIC, Nashua, NH

7 4:00 **Response of a Two-Wire Shielded Line to a Disturbing Wave,** B. Démoulin, L. Koné and P. Degauque, Université de Lille, France

8 4:20 **A New Look at Coupling to a Cable Above a Ground Plane,** L. O. Hoeft, J. S. Hofstra, and J. A. Latino, The BDM Corporation, Albuquerque, NM

6:30 Reception for foreign attendees at Stanford Park Hotel, Menlo Park

THE EFFECTS OF CAPACITIVE AND CONDUCTIVE COUPLING IN NETWORKS OF TRANSMISSION LINES

John D. Norgard *, J. Regnald Curry and Ronald M. Sega †

Mission Research Corporation
4935 North 30th Street
Colorado Springs, CO 80919

ABSTRACT

One dimensional time domain transmission line codes can be used to model arbitrary networks of conductors for SREMP coupling calculations. These codes, however, ignore mutual effects between cables. Both inductive and capacitive mutual effects have been neglected to the present time.

Mutual effects have traditionally been treated by three dimensional Maxwell equation solvers; however, 3D codes are significantly more complex and costly to run than are 1D codes. The use of 3D codes for parametric system studies are usually cost prohibitive. 1D transmission line equation solvers are presently being used to perform parametric studies on system models that would normally be treated by 3D codes. Mutual effects have been ignored to reduce code complexity and computer costs. To improve the accuracy of 1D codes for system analyses, the mutual coupling between system conductors should be included. This study was undertaken to resolve the mutual effects arising from the radial, scattered, electric fields; mutual inductance effects due to currents on conductors are ignored in this study.

This study compares the results from a 1D transmission line equation solver with results from the same solver modified to include mutual capacitance and conductance terms. These coefficients were derived from the solution of Poisson's equation in prolate spheroidal coordinates and were checked against analytical calculations based on the work of Sunde.

The results of this study indicate that mutual E-field coupling affects the prediction of induced currents on systems of conductors at late times. The inclusion of mutuals can significantly reduce injected current onto a network of buried lines since the impedance of the system is increased by mutual effects.

This work was sponsored by the Ballistic Missile Office (BMO) through a grant from the Defense Nuclear Agency (DNA).

*Also affiliated with the University of Colorado
†Also affiliated with the Univ. of Colo. and FJSRL, USAFA

Coupling phenomena in multiconductor screened telephone cables

B. DJEBARI - A. ZEDDAM - F. BRUNEL - R. LERAY

Centre National d'Etudes des Télécommunications
B.P. 40 - 22301 LANNION CEDEX - FRANCE

Abstract :

Overhead multiconductor screened cables are frequently used in the distribution part of the local french telephone network.

When a multiconductor cable is illuminated by an incident EM field, two kinds of EM interaction appear : an external interaction which leads to the calculation of the current and voltage distribution on the shield and an internal problem which concerns the evaluation of the common and differential mode voltages. In the case of the lightning EM pulse the common mode voltage could strongly stress the terminal equipments and in such circumstances efficient protection must be used. On the other hand the EM interferences caused for example by broad-cast radio transmitters are weak, but the recurrence of the disturbing differential mode voltage could affect the quality of the transmitted signal.

External interaction has been studied by many authors (1) and thus we shall focus our presentation on the internal interaction.

The internal coupling phenomena in the multiconductor cable is often investigated with the help of multiconductor transmission coupled line theory which needs the knowledge of the per unit-length impedance and admittance matrix.

An experimental method to determine the inductance and capacitance matrix was proposed by Agrawal et al [2]. We applied it to the case of the shielded multiconductor cable and developped an automatic wide band frequency system using a switching matrix.

This paper presents the measurement method, describes the automatic set up and gives the obtained results. The frequency band in which this method is valid is discussed. Using the measured matrix and the transfer impedance parameters of the shield we give the calculated response of one pair and two pair shielded telephone cables illuminated by a plane-wave EM field. The influence of the main parameters is discussed. Finally we compare the predicted results to those obtained by experimental illumination of the cables.

References :

[1] E.F. VANCE - Coupling to shielded cables
Wiley Interscience Publication N.Y. 1978

[2] A.K. AGRAWAL et al - Experimental caracterization of multiconductor transmission lines in the frequency domain.

MULTICONDUCTOR CABLE RESPONSE DEPENDENCY ON PROPAGATION MODES

J. Beilfuss
Harry Diamond Laboratories, DELHD-NW-ED,
2600 Powder Mill Road, Adelphi, MD 20783-1197

A. Bell, R. Gray, R. Hamrick
ENSCO, Inc., 5400 Port Royal Road
Springfield, VA 22151-2388

ABSTRACT

The ability to compute and simulate the response of a shielded multiconductor cable due to external fields is important for electromagnetic susceptibility and EMP studies of complex electronic systems. The response of the multiconductor cable may be analyzed using the work of Paul [1] if the distribution of the source vectors is known. A theoretical study of the distribution of the source vectors is presented. The distribution of the open circuit voltages is shown to be dependent on the modes of propagation for the cable. Since most multiconductor cables are not homogeneous due to different dielectrics and varying wire lay, they may have multiple modes of propagation.

The results of experiments on a multiconductor cable will be presented along with comparisons to theoretically expected responses. The cause of the variations in the open circuit voltages will be discussed. The analysis of the experimental data includes the use of a maximum entropy spectral estimation technique [2] in order to determine the modes of propagation present on the individual wires.

This paper presents a theoretical and experimental study of the response of shielded multiconductor cables to external transient fields. Of primary interest is the distribution of the induced voltages at the ends of the cables under open circuit load conditions. Knowledge of the open circuit voltage distribution and the cable impedance matrix allows computation of the cable response under any other loading condition. This study establishes a direct relationship between the modes of propagation on the wire and the open circuit voltage from the wire to the shield.

References:

1. C. R. Paul, "Efficient Numerical Computation of the Frequency Response of Cables Illuminated by an Electromagnetic Field", IEEE Transactions on Microwave Theory and Techniques, Vol-52, No. 4, April 1974, pp 454-457.

2. S. M. Kay, S. L. Marple, Jr., "Spectrum Analysis - A Modern Perspective", in Proceedings of the IEEE, Vol. 69, No. 11, Nov., 1981, pp 1380-1419.

COMMON-MODE VOLTAGE INDUCED ON A MULTI-WIRE SHIELDED CABLE ILLUMINATED BY AN ELECTROMAGNETIC PULSE

A. Zeddam

Centre National d'Etudes des Télécommunications
Dept ELR/DNP, B.P. 40, 22301 Lannion, France

P. Degauque

Université de Lille 1, Electronics Dept.
59655 Villeneuve d'Ascq Cédex, France.

Multi-wire shielded lines are extensively used in the telecommunication network and are either situated above the ground surface at a height of about 6 m or embedded at a depth of 1 m. At the ends of these cables, sensitive equipments are connected and must be protected efficiently. Usually common-mode overvoltages are suppressed by arrestors. If necessary additional devices can be used for the differential mode. This becomes critical with the advent of the integration service in digital network (I.S.D.N.) since the level of the transmitting signals are much smaller than previously. Therefore, it is of great importance to determine the waveshape of the disturbing signals appearing at the ends of the cable to optimize the protecting devices. In this paper we first describe the external problem in frequency domain to point out the influence of geometrical and electrical factors such as the angle of incidence of the disturbing wave, the cable length, the ground conductivity, etc... Furthermore, resonances of the structure are studied for various conditions of excitation and of load impedances. Then the time response is computed through Fast Fourier Transforms routines. The common-mode voltage being defined as the voltage appearing between the bundle of inner wires, short-circuited at both ends, and the shield, it can be expressed in terms of transfer impedance. Some examples are given to compare the waveshape of the voltage to the one of the induced current flowing on the outer shield. An extensive study of the differential-mode voltages is given in another presentation |1|.

|1| B. Démoulin, L. Koné and P. Degauque, "Response of a two-wire shielded line to a disturbing wave", submitted to NEMP Meeting, 1988.

INDUCTIVE AND CAPACITIVE COUPLING OF TRANSIENTS TO TRANSMISSION LINES

F.M. Weitze, J.L. ter Haseborg, A. Jordan
Technical University Hamburg-Harburg
P.O. Box 90 14 03 2100 Hamburg 90

With growing integration of electronic circuits, vulnerability of electronic systems increases. Apart from field tests the pulse injection to transmission lines becomes more and more important because interfering electromagnetic fields, e.g. caused by LEMP or NEMP, primarily induce currents on the cable shield. Dependent on the transfer impedance or transfer admittance respectively, part of the sheath current is coupled into the inner conductors. Concerning the disturbances or even destructions of sensitive electronic components the interfering currents at the line terminations are of interest.

The coupling of electromagnetic fields to cables shows an inductive as well as a capacitive component. Coupling can be simulated by a clip-on probe which essentially consists of a strip line. Similar devices are commerically available.

By means of these clip-on probes in terms of a strip-line not only a capacitive but also an inductive coupling component can be realized. Varying the clip-on probe termination from short circuit to open circuit the coupling ranges from dominating inductive via inductive/capacitive to dominating capacitive mode. The test set-up consists of a defined transmission line, terminated in its impedance at both ends, and the clip-on probe, driven by a pulse generator, arranged in the middle of the line. In case of a multiconductor transmission line the measurement results in the time domain show the voltages at both line terminations dependent on different terminations of the clip-on probe. The results obtained allow a quantitative estimation between inductive and capacitive coupling. Starting from the measurements an equivalent circuit considering the different coupling modes will be presented.

Effect of Risetime on Coupling to Short Cables

Llewellyn Jones and Allison Cyganowski

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
61 Spit Brook Road, Suite 204
Nashua, NH 03060

EMP specifications now include a faster risetime high altitude environment than in the past. This paper discusses the system hardening ramifications of the risetime of the environment on coupling to short shielded multiconductor cable assemblies along with the resulting transients. Coupling analysis has been performed using both LPN and analytical methods with a range of risetimes from 1 nanosecond to 20 nanoseconds on cables 1 to 5 meters in length. The effect of typical transfer impedance versus frequency has been incorporated.

This work supported by Harry Diamond Laboratories under Contract DAAL02-86-D-0041.

RESPONSE OF A TWO-WIRE SHIELDED LINE TO A DISTURBING WAVE

B. Démoulin, L. Koné and P. Degauque

Université de Lille 1, Electronics Dept.,
59655 Villeneuve d'Ascq Cédex, France.

We present in this paper a theoretical and experimental approach to determine the response of a two-wire shielded line illuminated by an electromagnetic wave. The external problem and the principle of the calculation of the common-mode voltage are presented elsewhere |1|. We emphasize the various coupling mechanisms which can give rise to a differential voltage. Furthermore, the variation of this voltage with the cable length is especially studied.

For electrically short cables it is possible to introduce common-mode and differential mode transfer impedances from measurements of the disturbing voltages appearing at the ends of the cable. The differential transfer impedance Z_{td} corresponds to a direct induction of a differential mode due to a dissymmetry in the cable geometry. For example if Z_{t1} and Z_{t2} are the transfer impedances associated respectively with the inner wires 1 and 2, Z_{td} is given by the difference of these two values. However a common mode to differential mode conversion can also occur due, for example, to unbalanced load impedances, to a dissymmetry in the position of the inner wires, etc... A simple analytical formulation shows that this mode transfer varies as the square of the cable length. Usually the resistance of the inner wires are neglected. However for long cables, this factor can change the cable response. We present on some examples the modification of the peak voltage and of the energy of the disturbing pulse at the ends of the cable due to this effect.

|1| A. Zeddam and P. Degauque, "Common-mode voltage induced on a multi-wire shielded cable illuminated by an electromagnetic pulse", submitted to NEMP Meeting, 1988.

A NEW LOOK AT COUPLING TO A CABLE ABOVE A GROUND PLANE

Lothar O. Hoeft, Joseph S. Hofstra, and Joseph A. Latino
The BDM Corporation
1801 Randolph Rd., S.E.
Albuquerque, NM 87106
(505) 848-5399

The traditional analysis of this problem predicts that the current is proportional to the loop area, therefore to the height of the wire above the ground plane, and inversely proportional to the self impedance (inductance). The inductance is proportional to the inverse hyperbolic cosine of the ratio of the cable centerline height to is radius. The centerline height is replaced by the sum of the cable radius and the height of the bottom of cable above the ground plane (as used in the loop equation) so that the entire analysis uses the same reference dimensions. If the bottom of the cable is less than a few cable diameters above the ground plane, the inverse cosh function can be approximated by the square root of the ratio of the height to radius. Substituting this into the loop equation shows that if the bottom of the cable is less than a few cable diameters from the ground plane, the current induced in the wire is proportional to both the magnetic field and the square root of the product of the cable radius and the height of the bottom of the cable above the ground plane. If the cable height is many times its diameter, the cable's self inductance is only a weak function of its dimensions and the traditional formulation is appropriate. Experimental measurements using a variety of cable heights and diameters confirm the square root dependence. These measurements also suggest that the cable current does not go to zero when the cable is laying on the ground plane.

SESSION 2B-1

SENSORS AND INSTRUMENTATION: MEASUREMENT, RECORDING, AND DATA PROCESSING SYSTEMS II

Chairman: T. Smith, Air Force Weapons Laboratory, NM
Monday, 16 May (afternoon) Building A, Conference Room B

1 1:30 **Overview of Broadband CW Characterization and Processing Technology**, R. J. King, Lawrence Livermore National Lab., CA

2 1:50 **Analysis and Design of Broadband Antenna for Anechoic Chamber Illumination**, C. Cheon and V. V. Liepa, The University of Michigan, Ann Arbor, MI

3 2:10 **Production of Uniform Electrostatic Fields by a Slotted Conducting Spherical Shell**, C. E. Baum, AFWL, NM

4 2:30 **An Optically Powered Electro-Optical Transmission System for EMP / EMC Measurements**, K.-D. Kruse and J. L. ter Haseborg, Technical University Hamburg-Harburg; J. Nedtwig AEG-Ulm, West Germany

SESSION 2B-2

INTERACTION: EM COUPLING I

Chairman: P. Castillo, R&D Associates, Albuquerque, NM
Monday, 16 May (afternoon) Building A, Conference Room B

1 3:20 **Effects of a Lossy Dielectric Layer on the Concentric Spherical Cavity Resonances**, L. Libelo and G. Pisane, HDL, Adelphi, MD

2 3:40 **Electromagnetic Interaction with Anisotropic Structures Whose Regions of Continuity of Conductivity, Permittivity, and Permeability Tensors may be Delimited by Impedance Sheets**, D. Cohoon

3 4:00 **Mathematical Techniques for Description of Electromagnetic Wave Propagation and Interaction in Dusty, Dispersive Media**, G. R. Akers, E. Systems, Inc., Greenville, TX

4 4:20 **Numerical and Experimental Techniques for Determining Coupling Through Composite Materials with Various Contact Impedances**, V. Gobin, Avions Marcel Dassault/ Bréquet Aviation and G. Labaune, Office National d'Etudes et de Recherches Aérospatiales, France

6:30 Reception for foreign attendees at Stanford Park Hotel, Menlo Park

Overview of Broadband CW Characterization and Processing Technology

R. J. King

Lawrence Livermore National Laboratory

P. O. Box 808, L-156

Livermore, CA 94550

Characterization of linear coupling can now be achieved using broadband cw state-of-the-art facilities and instrumentation systems. Modern automatic network analyzers driven by synthesized frequency sources are capable of essentially measuring the spectral components of the impulse response in both amplitude and phase with unprecedented accuracy, sensitivity and dynamic range. Frequency resolutions of a few Hz and accuracies of a few tenths of a dB and a few degrees are readily achievable using precision techniques for calibration of the instrumentation system and the sensors. Further, once the spectral impulse response is measured, it can be multiplied by the spectrum of an arbitrary assumed temporal signal and then inverse transformed to yield the temporal response of the system to the impressed temporal waveform. In this manner, the need for making the transient measurements is eliminated.

This presentation will address the key issues required to achieve these capabilities: automated instrumentation systems, anechoic facilities, direct sensor calibration, and data acquisition/processing/display. Specific examples will be given.

ANALYSIS AND DESIGN OF BROADBAND ANTENNA FOR ANECHOIC CHAMBER ILLUMINATION

Changyul Cheon and Valdis V. Liepa
Radiation Laboratory
Department of Electrical and Computer Engineering
The University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT

To illuminate a tapered 60-foot anechoic chamber for scale model measurements a 4-wire VV antenna is analyzed. A 2-wire V antenna is first studied to determine the optimum quadiatic end loading for minimum current reflection. These results are then applied to a 4-wire geometry which is then optimized to produce uniform linearly polarized field over the test region for frequencies 100 MHz to 1 GHz.

Analysis was made using LLL NEC code. Both V and VV antennas exhibit relatively uniform input impedance (approximately 120 - j70 ohms and 80 - j40 ohms, respectively) and the VV antenna produces a uniform field within ±0.5 dB within a 2-meter diameter spherical test region. This field uniformity is achieved height-to-width ratio 1: $\sqrt{3}$ (horizontal polarization), but when the wires are placed symmetrically (1:1 ratio), a structure which could accommodate either horizontal or vertical polarization, the field uniformity is ±1.0 dB over the same test region.

PRODUCTION OF UNIFORM ELECTROSTATIC FIELDS
BY A SLOTTED CONDUCTING SPHERICAL SHELL

C. E. Baum
Air Force Weapons Laboratory
Kirtland AFB
Albuquerque, New Mexico 87117-6008

For some applications one desires a uniform quasi-static electric field. Along the lines already well developed concerning magnetostatic fields, in this case electric potential is specified on a spherical surface. Dividing the surface on lines of constant latitude (polar angle) the resulting bands are constrained to have particular voltages. The particular case of three conducting surfaces with voltages V_1, 0 and $-V_1$ is considered in detail with optimum angles θ_1 and $\pi - \theta_1$ with $\theta_1 \simeq 63.43^\circ$. This makes for a very uniform electic field near the center of the sphere.

AN OPTICALLY POWERED ELECTRO-OPTICAL TRANSMISSION SYSTEM FOR EMP/EMC MEASUREMENTS

K.-D. Kruse, J.L. ter Haseborg
Technical University Hamburg-Harburg
P.O. Box 90 14 03 2100 Hamburg 90
West Germany
J. Nedtwig AEG-Ulm
P.O. Box 1730 7900 Ulm
West Germany

An electro-optical system has been developed for measuring comparatively low currents in an electromagnetic environment, e.g. in EMP-simulators. The set-up consists of the transmitter, which may be connected with the field probe or current probe respectively, a signal fiber optic cable, a second fiber optic cable for supplying the transmitter, and the receiving unit including the power supply. The system, covering a 3dB-bandwith between 1 kHz and 100 MHz, allows measurements in the mV/mA-range. Similar devices are commercially available. The special characteristic of this set-up presented is a continuous optical power supply for the transmitter which is independent on batteries with their limited service life. Therefore continuous measurement or monitoring for an arbitrarily long time is possible.

The transmitter consists of a laser-diode with a 50/125 µm-pigtail, a matching network, a special overvoltage protection, and the solar module for the power supply. The device, characterized by its comparatively small dimensions, is mounted in a cylindrical box (Ø = 31 mm, length = 100 mm) and connected via the fiber optic cable with a fast SI-PIN-diode as opto-electronic transmitter and the registration unit e.g. an oscilloscope. A further reduction of the box is in process. By means of a control unit which drives a 150 W-halogen lamp, providing light via a fiber optic cable (Ø = 8 mm) to the solar generator in the transmitter, a stabilization of the operating point of the laser diode is realized.

The output power of the laser diode is adjusted to half of the maximum power output of 6 mW. In case of defects concering the signal fiber optic the control circuit limits the maximum power output of the laser diode and an error message occurs. The transmitter may be connected with 50 Ω-current/field probes. The measurement range may be changed by different attenuators between probe and transmitter. The integrated overvoltage protection circuit for the laser diode will be described in a further publication. The system has been tested in a TEM-cell which offers an electric field strength up to 50 kV/m with a rise time of 10 ns. The measurement set-up and results will be shown and discussed.

EFFECTS OF A LOSSY DIELECTRIC LAYER ON THE CONCENTRIC SPHERICAL CAVITY RESONANCES

L. LIBELO AND G. PISANE, The Harry Diamond Laboratories, Adelphi MD 20783

As a result of its broad range of practical electromagnetic applications the conducting finite cavity has been subjected to considerable investigation over the years. There still remains, however, a great deal to learn about such systems. In the case of loaded cavities this is especially true.

We have been investigating the characteristics of the loaded concentric spherical cavity. This is one of the very few finite systems that can be studied analytically. Results obtained for this system can generate substantial insight into the characteristics of cavity systems of greater complexity. In the course of our research we have developed techniques for systematically studying cavity systems for general ranges of frequency in addition to unearthing some very interesting and important properties of the loaded cavity.

We show results obtained for effects on the cavity resonances that arise from loading the inner conductor with a lossy dielectric layer. These effects have been studied for the complete range of the layer varying from a perfect dielectric to a perfect conductor and over the entire allowed range of the inner conductor radius. The variety of the characteristics of the results are of practical significance in better understanding coupling phenomena in the case where the cavity contains ports of entry such as apertures.

ELECTROMAGNETIC INTERACTION WITH ANISOTROPIC STRUCTURES WHOSE REGIONS OF CONTINUITY OF CONDUCTIVITY PERMITTIVITY AND PERMEABILITY TENSORS MAY BE DELIMITED BY IMPEDANCE SHEETS

D. Cahoon

ABSTRACT:

A uniqueness theorem is established for the interaction of electromagnetic radiation with anisotropic structures delimited by impedance sheets.

An exact solution is provided for special anisotropic structures whose regions of continuity of electromagnetic properties are delimited by concentric spheres. For this structure an energy balance calculation is carried out involving verification of equality between sums of surface integrals over separating impedance sheets and volume integrals of electric and magnetic power densities over the open sets bounded by these impedance sheets.

A second exact solution is obtained when these complex materials are delimited by coaxial cylinders.

The above structures are both special cases of anisotropic bodies of revolution, which are structures whose regions of continuity of tensor electromagnetic properties can be delimited by nonintersecting surfaces of revolution.

An electromagnetic scatterer can be conceptualized as function from $R^3 x C_\omega$ into C^{27}, complex 27 dimensional space. With some restrictions on these functions which represent permittivity, permeability, and conductivity tensors as a function of points in R^3 and a complex frequency in C_ω a uniqueness theorem and integral and differential equation formulations and methods of solution are established. These include a hybridization of an exact finite rank integral equation mehtod and a resolvent kernel method involving Ricatti integrodifferential equations.

NAME OF AUTHOR: Dr. Geoffrey R. Akers

ADDRESS: E-Systems, Inc.
P.O. Box 1056
Tactical Systems Division
Mail Stop 96
Greenville, TX 75401

TITLE: Mathematical Techniques for Description of Electromagnetic Wave Propagation and Interaction in Dusty, Dispersive Media

NUMERICAL AND EXPERIMENTAL TECHNIQUES
FOR DETERMINING COUPLING THROUGH COMPOSITE MATERIALS
WITH VARIOUS CONTACT IMPEDANCES

by V. Gobin
Avions Marcel Dassault/Bréguet Aviation
78, quai Carnot, 92210 Saint Cloud, France

and G. Labaune
Office National d'Etudes et de Recherches Aérospatiales
BP 72, 92322 Châtillon Cedex, France

This paper discusses the electromagnetic field penetration through composite materials. The presentation insists on the shielding degradation due to contact impedance between materials.

The numerical results are based upon integral equation formalism including materials represented by a surface impedance and joints between materials modelised by a surface impedance. The numerical solutions are compared to the theoretical model proposed by Casey [1] for circular aperture. Various experimental measurements conducted on TEM cell an Faraday cage are presented. When shielding is measured with two circular loops (as suggested by Mil STD 28S measurements), the role of antenna orientation and joint quality is discussed.

Numerical results are presented for non circular loaded apertures and 3D composite structures.

[1] Casey, K.F., "Low frequency electromagnetic penetration of loaded apertures" IEEE Trans. on Electromagnetic Compatibility, EMC23, 4, Nov. 1981.

SESSION 2C

SIMULATION II

Chair: J. Quinn, Materials Research Lab, Melbourne, Australia
Monday, 16 May (afternoon) Building I, Auditorium

1 1:30 **A Definition of Pulse Rise Time, Peak Amplitude, and Decay Time Based Upon a Fit of Data to an Ideal Reciprocal Double-Exponential Waveform**, G. D. Sower, EG&G WASC, NM

2 1:50 **Effective Rise Time Resulting from a Convolution of Waveforms with Exponential and Gaussian Rise Characteristics**, D. V. Giri, Pro-Tech, Berkeley, CA

3 2:10 **Breakdown of Uniform Field Pressured SF_6 Spark Gaps as a Function of Charge Time**, I. Smith, Pulse Sciences, Inc., San Leandro, CA

4 2:30 **Early Time Performance at Large Distances of Periodic Arrays of Flat-Plate Conical Wave Launchers**, D. V. Giri, Pro-Tech, Berkeley, CA; C. E. Baum, AFWL/NTAAB, Kirtland AFB, NM

2:50 Coffee Break

5 3:20 **Approximate Design Criteria and Performance Estimates for a Distributed Switch Array Based on Spark Gaps**, I. Smith, Pulse Sciences, Inc., San Leandro, CA

6 3:40 **Radiated EM Field Near a Parallel Plate Antenna**, B. Djebari, Centre National d'Etudes des Télécommunications, Lannion, France; P. Morin, ETCA, France

7 4:00 **EMP Research in India: Relevance and Present Status**, G. R. Nagabhushana, Indian Institute of Science; Col. G. K. Deb, LRDE, Bangalore, India

8 4:20 **The Far Field from an HPD Simulator with a Short Rise-Time Pulser**, S. Garmland, Swedish National Defense Research Institute (FOA), Linköping, Sweden

6:30 Reception for foreign attendees at Stanford Park Hotel, Menlo Park

A DEFINITION OF PULSE RISE TIME, PEAK AMPLITUDE, AND DECAY TIME BASED UPON A FIT OF DATA TO AN IDEAL RECIPROCAL DOUBLE-EXPONENTIAL WAVEFORM

G.D. Sower

EG&G Washington Analytical Services Center, Inc.
P.O. Box 9100
Albuquerque, NM 87119
Telephone No. (505) 243-2233

ABSTRACT

Most pulsed-power sources, particularly in the EMP community, are required to meet or exceed specifications pertaining to the rise time of the pulse. The most common specification is defined as the time between the ten-percent and ninety-percent levels of the pulse peak amplitude. Such a definition is very meaningful and precise when applied to an analytical (criterion) waveform such as a double-exponential or a reciprocal double-exponential waveform. However, problems usually arise in real waveforms wherein noise, prepulse, overshoot, ringing, reflections, and other fluctuations create significant deviations from the criterion waveform.

This paper proposes a new method of defining pulse rise time and peak amplitude which is both easy and meaningful in terms of both a physicalLy realizable EMP signals and also in terms of the physics of pulsed power generators. It is the reciprocal double exponential which has already gained wide acceptance in the community[1]. This waveform is completely described by three parameters, pulse amplitude, rise time, and decay time. It is proposed that these parameters be obtained by an appropriate fit to the data, and that the compliance to the specifications be determined from the resulting analytical waveform. The difference between the analytical waveform so obtained and the data from which it is obtained is then a deviation from the desired signal, which must be within allowable limits.

---

1. C.E. Baum, "Some Considerations Concerning Analytic EMP Criteria Waveforms," AFWL, TN285, October 1976

EFFECTIVE RISE TIME RESULTING FROM A CONVOLUTION OF WAVEFORMS WITH EXPONENTIAL AND GAUSSIAN RISE CHARACTERISTICS

D. V. Giri
Pro-Tech, 125 University Avenue, Berkeley, CA 94710

Abstract

In this paper, we investigate how certain waveforms with known rise characteristics combine to produce the resulting waveform. For example, if one wishes to combine two exponentially rising waveforms, linear addition or quadrature addition of individual rise times (e-folding or maximum slope [1]) can give estimates of the combined waveform's rate of rise. The method used here consists of convolving the waveforms to determine the frequency spectrum of the combined waveform. Then the frequency at which this spectrum is reduced in magnitude by an amount of $(1/\sqrt{2})$ from that of an ideal - step-function spectrum is determined. The reciprocal of this frequency is then defined as the effective rate of rise of the combined output waveform.

Two examples are worked out. One consists of combining two exponentially rising waveforms, for which the resulting rise rate is available in closed form. The second example is that of combining an exponentially rising waveform with that of an integrated Gaussian distribution. In both cases, the results of the present method fall in between linear and quadrature estimates.

---

[1] C. E. Baum, "Some Considerations Concerning Analytic EMP Criteria Waveforms," Theoretical Note 285, 29 October 1976.

BREAKDOWN OF UNIFORM FIELD PRESSURIZED SF_6 SPARK GAPS AS A FUNCTION OF CHARGE TIME

Ian Smith
Pulse Sciences Inc.
600 McCormick Street
San Leandro, CA 94577

Abstract

A survey of available literature and existing simulators has been made to determine the breakdown field strengths of pulse charged SF_6 spark gaps, in particular when they are rapidly charged as in a distributed switch array or peaking circuit.

EARLY TIME PERFORMANCE AT LARGE DISTANCES OF PERIODIC ARRAYS OF FLAT-PLATE CONICAL WAVE LAUNCHERS

D. V. Giri
Pro-Tech, 125 University Avenue, Berkeley, CA 94710

and

Carl E. Baum
Air Force Weapons Laboratory/NTAAB
Kirtland AFB, New Mexico 87117

Abstract

Many techniques have been investigated for the purpose of launching transient electromagentic (EM) waves and the results have been incorporated in the design of various categories of EMP simulators. One such technique involves configuring many sources into an array. The source array synthesizes an appropriate aperture field distribution to launch a desired type of wave. The individual sources are interconnected in some series-parallel fashion, via conducting surfaces which have a significant impact on the early-time rate of rise in the distant field. Both planar and non-planar arrays have been considered in the past.

In this paper, we consider some possible geometries of unit cells in the distributed source or distributed switch wave launchers. Attention is focussed on one aspect of performance, i.e., the rate of rise in the far field (for assumed ideal step-function sources) of candidate unit cell designs. The unit cells considered are planar-conical or non-planar wave launchers. There are perhaps many module or unit-cell designs one may consider, each being associated with its own boundary value problem. Two illustrative examples are presented. Formulae for the early-time rate of rise are developed, tabulated and plotted, as a function of normalized geometrical parameters of an individual launcher and the array.

APPROXIMATE DESIGN CRITERIA AND PERFORMANCE ESTIMATES FOR A DISTRIBUTED SWITCH ARRAY BASED ON SPARK GAPS

Ian Smith
Pulse Sciences Inc.
600 McCormick Street
San Leandro, CA 94577

This paper provides risetime calculations for a gas switched distributed switch array that could be used to launch EMP waves. The distributed switch array has been proposed as a technique for overcoming the risetime limitations of a single switch launcher where it has been shown that risetime increases with source voltage. The distributed switch concept uses a distribution or array of switches and wavelaunchers of lower voltage and size to overcome this limitation. Switch jitter, wavelauncher geometry and dimensions, and switch inductance effects are considered in the calculations presented.

Radiated EM field near a parallel plate antenna

B. DJEBARI* - P. MORIN**

*Centre National d'Etudes des Télécommunications
(LAA/ELR/DNP) - BP 40 - 22301 LANNION CEDEX - FRANCE

**ETCA - 16, avenue Prieur de la Côte d'Or
94140 ARCUEIL - FRANCE

Abstract :

An important type of simulator used in NEMP studies is one consisting of a parallel plate open wave guide with tapered triangular ends. It is known that at low frequencies the propagating mode is TEM and the radiated EM field outside is negligible. At high frequencies most of the power applied to the input is radiated and can disturb the site around the simulator.

In 1980 the CNET built a 80 kV parallel plate antenna. In 1987 a large one of the same type was built in order to test electronic telephone equipments. As both antennae are located near an airport and electronic laboratories, EM field measurements were made on the 80 kV antenna before selecting the site and the orientation of the new one.

This paper presents the measurements (near the ground and airborne using a helicopter) analyses the results and compares them to those given by a horizontal progressive wave antenna.

EMP RESEARCH IN INDIA RELEVANCE & PRESENT STATUS

Dr.G.R.Nagabhushana
Department of High Voltage Engg.
Indian Institute of Science

Col.Dr.G.K.Deb
LRDE,

Bangalore, INDIA

Over the last decade, sensitive electronics have come into wide usage in India. Such electronic instrumentation being vulnerable to transient overvoltages, effort is required to harden them. The more serious threats are due to LEMP & NEMP but the former is relatively less important. NEMP today is a worldwide threat and therefore it is necessary to take sufficient precautions to meet this eventuality however remote.

This presentation reports on the present status of NEMP research in India which is presently at low level. A parallel plate simulator of working volume 2m X 2m X 2m with an E field of 10kV/m to 50kV/m, wave shape 10ns/250ns, is under construcion. The instrumentation proposed to be tested for performance are a few computer system, automatic telephone exchanges, communication equipment and a few other electronic instruments. This small facility will also be used for training of some personnel in this area.

THE FAR FIELD FROM AN HPD SIMULATOR WITH A SHORT RISE-TIME PULSER

SVEN GARMLAND
SWEDISH NATIONAL DEFENSE RESEARCH INSTITUTE (FOA)
BOX 1165, S-581 11 LINKÖPING, SWEDEN

When EMP simulators are being used there is always a risk of disturbance on electronic systems in the nearby surroundings. In order to prevent this, it is important to analyse the far field characteristics of the simulator antenna prior to high level testing.

To establish a proper model of the far field radiation of SPERANS, one of the Swedish EMP simulators, both the electric- and the magnetic fields were measured with a mobile measurement system at a number of points in the surrounding area. SPERANS is a hybrid EMP simulator (HPD). It consists of a fast rise-time, 100kV-pulser suspended 20 meters above ground, driving a bicone radiator connected to a 60 meters long horizontally polarized dipole. The dipole is resistively loaded and connected to ground for proper late time characteristics, thus forming a half ellipsoid.

Earlier, it has been shown that the radial (with respect to the bicone) far field radiation from HPD-simulators is much lower than the axial. The measurements presented in this paper show that when a short rise-time pulser is used this is no longer true. In the radial direction the far fields can be predicted by considering the bicone radiator as the only significant source. Fields emitted from the rest of the antenna will be essentially shorted by the ground. Because of the short rise-time, the horizontally polarized wave emitted in the radial direction reaches an extensive peak before it is reduced by the ground-reflected wave.

This paper shows how the peak amplitude can easily be predicted considering only the pulser/bicone characteristics and the ground reflection clear-time. The rise-time will be approximately equal to the ground reflection clear-time and the pulse duration also very short. In the axial direction on the other hand the radiated wave is essentially vertically polarized and thus the ground reflection enhances the field. Considering the peak amplitude this implies that the radiation from an HPD simulator with a fast rise-time source is almost omni-directional.

Because of the extremely short ground reflection clear-time at a long distance from the simulator, the rise-time of the field becomes very short. It is therefore of great importance that the measurement system has sufficiently large bandwidth. This paper also presents the measurement system and the design of the fast rise-time pulser.

SESSION 3A
ASSESSMENT: TECHNIQUES

Chair: G. Bechtold, Naval Surface Warfare Center., White Oak, MD
Tuesday, 17 May (morning) Building I, Auditorium

1 8:30 **High Level Pulse versus Low Level CW EMP Simulator Response Comparisons**, S. Kokorowski, C. Zuffada, and J. Martinez, Kaman Sciences Dikewood Div.; T. Smith, AFWL; W. Bereuter, MRC

2 8:50 **Establishing a Correlation of Shelter Shielding Effectiveness Between HEMP and CW Excitations**, Y. M. Lee, J. Latess, and B. T. Benwell, Harry Diamond Laboratory, Adelphi, MD

3 9:10 **In-Field Hardness Surveillance of Penetration Protection Devices**, K. R. Jurisson and R. T. Zeitler, TRW, Albuquerque, NM

4 9:30 **Point of Entry (POE) Detection and Location**, H. T. Davis, Dikewood Consultant; K. Gallegos, AFWL

5 9:50 **A Portable Test Set for EMP Hardness and Assuredness Testing at the Pin Level**, B. R. Tolmie, Joselyn Defense Systems, Shelburne, VT

10:10 Coffee Break

6 10:40 **An Automated Multi-Pin Test System for Direct Pin-Drive Testing**, A. J. Bonham and M. E. Gruchalla, EG&G WASC, NM

7 11:00 **A Modular EMP Pulser System and Data Acquisition Unit for Transient Field Generation and Current Injection**, D. Koenigstein, D. Hansen, and H. Schaer, ASEA Brown Boveri Corp., Switzerland

8 11:20 **SLEET - Foundation for Advanced Analysis**, M. E. Butler, F. C. McCloskey and M. P. Walker, TRW, Albuquerque, NM

9 11:40 **Responses of Five HAMS Sensor/Drivers**, R. H. St. John and E. A. Callan, MRC, Albuquerque, NM

HIGH LEVEL PULSE VERSUS LOW LEVEL CW EMP SIMULATOR RESPONSE COMPARISONS

S. Kokorowski
C. Zuffada
J. Martinez
Kaman Sciences Corporation
Dikewood Division

T. Smith
Air Force Weapons Laboratory

W. Bereuter
Mission Research Corporation

ABSTRACT

During the summer of 1987 the Air Force Weapons Laboratory (AFWL) conducted extensive EMP testing using its EMP test aircraft (EMPTAC). This testing included high level pulse (HLP) as well as low level CW (LLCW) illumination of the EMPTAC. Response data was obtained in the Trestle and VPD-II HLP facilities, at common test points, for both horizontally and vertically polarized incident electric fields. Different aircraft orientations relative to the incident field were also investigated. Predictions of the HLP responses have been obtained using the measured LLCW data. One type of prediction technique makes use of measured incident field responses, in the absence of the test object, in both the HLP and LLCW facilities. Another type of prediction technique uses the surface responses measured on the EMPTAC to predict the internal responses. Comparisons of the predicted versus the measured responses will be presented, for several different aircraft illumination conditions. A description of the prediction techniques will also be presented. The advantages and disadvantages of each prediction technique will be reviewed and compared. In addition, extrapolation to an unclassified threat criterion environment have been performed on both the HLP and LLCW response data. Comparisons of the extrapolated results will be presented. All the comparisons described above will be performed in the time and frequency domains and by calculating the waveform norms of the different response data sets.

Establishing a Correlation of Shelter Shielding Effectiveness Between HEMP and cw Excitations

Youn M. Lee, John Latess, Bruce T. Benwell
Dept. of the Army Laboratory Command
Harry Diamond Laboratory
2800 Powder Mill Road
Adelphi, MD 20783-1197

A preliminary correlation between the shielding effectiveness (SE) of a tactical shelter when excited by high-altitude electromagnetic pulse (HEMP) and continuous wave (cw) sources has been experimentally determined. This correlation permits current HEMP SE tests to be replaced by the much less expensive, commercially used, cw SE tests for a given shelter design.

The Army EMP Simulator Operation (AESOP) was used for the simulated HEMP source. HEMP SE was obtained using the definition

$$SE = 20 \log_{10} \left[\frac{F[\,H(t)^{ext}]}{F[\,H(t)^{int}]} \right] \qquad (dB),$$

where $H(t)^{ext}$ is the dominant magnetic field component measured at the shelter location without the presence of the shelter, and $H(t)^{int}$ is the dominant internal magnetic field component at a predetermined test point showing the worst-case cw SE. F[ ] represents the Fourier transform. A modified MIL-STD-285 test was conducted on all seams throughout the shelter to determine the worst-case cw SE. The modified MIL-STD-285 test was necessary to minimize the variations in current cw SE measurements, thereby allowing for a more accurate correlation between HEMP and cw SE. The modified MIL-STD-285 procedure showed improved day-to-day SE repeatability compared to traditional MIL-STD-285 techniques.

For this effort an unmodified Army S280C tactical shelter was chosen to limit the major electromagnetic field penetrations to the wall which contained the door and escape hatch. This configuration simplified the coupling analysis and reduced measurement time. The S280C shelter currently uses a mesh gasket with a silicon sponge core to shield these penetrations. The SE of this type of gasket deteriorates quickly over time with SE values falling below the required 60-dB margin as quickly as two months after installation. The seam impedance of this gasket type also varies under normal use. To eliminate these uncertainties the correlation effort was performed without a gasket present.

IN-FIELD HARDNESS SURVEILLANCE OF PENETRATION PROTECTION DEVICES

K.R. Jurisson
R.T. Zeitler

TRW Defense Systems Group
Albuquerque, New Mexico 87106

Hardness Surveillance testing of penetration protection devices (PPDs) can be done using continuous wave (CW) and low level direct drive (LLDD) techniques. Once PPD configurations have been qualified to threat at high levels in a laboratory environment, low level pulse data and insertion loss data are obtained on the final PPD design. The LLDD and CW data are used as baseline measurements for comparison to in-field testing. Low level direct drive data are taken with a portable pulse generator which is used to characterize the PPD electrical surge arrestor (ESA) and filter responses at levels well below damage thresholds. A storage oscilloscpoe is employed to capture the transient response of the PPD into a specified termination load and to measure the clamping level of the ESA. A network analyzer is used to measure insertion loss of the filter with a known load attached. Data are then compared to the baseline data set to determine if damage or degradation has occurred to a PPD.

POINT OF ENTRY (POE) DETECTION AND LOCATION

H.T. Davis
Dikewood Consultant

and

Karen Gallegos
Air Force Weapons Laboratory

ABSTRACT

The basic problem for maintaining the hardness of a system to an EMP threat is detecting and locating degradations in the hardening measures applied to the system. Since part of the protection will typically be the enclosure containing the vulnerable equipment, part of the detection and location problem then pertains to degradations in this protective enclosure.

The methods proposed in this paper are founded upon the most powerful statistical tests of the null hypothesis that a degradation has not occurred. The method is to reject this null hypothesis when degradation has occurred and, hence, give a sound probabilistic basis to the conclusions obtained from periodic hardness surveillance test data. Likewise, the probability of detecting a specified level of degradation is obtained from the power of the statistical tests, so that the optimum number of test points can be determined.

Also contained in this paper are methodologies to locate possible points of entry (POEs) for EMP energy. These methods are derived from multivariate statistical analysis. The methods are parameter descriptive in nature, rather than based on hypothesis testing, and provide powerful methods of combining information from several test points simultaneously to produce an amplified picture of hardening degradation information.

ABSTRACT

TECHNICAL SESSION: Nuclear Effects on Communications Systems

TITLE: A Portable Test Set for EMP Hardness and Assuredness Testing at the Pin Level.

AUTHOR: Bernard R. Tolmie
Joslyn Defense Systems, Inc.
2085 Shelburne Road
Shelburne, VT 05482
(802) 985-8621

Systems designer of military communications and weapons systems are increasingly required to provide systems survivability to such nuclear effects as electromagnetic pulse (EMP).

EMP presents an increasing threat to electronics in communications and weapons systems. These systems require EMP susceptibility testing at the pin level in the field to assure hardening over the operational life of the system. Hardened systems in the field are susceptible to degradation for the following reasons:

1) Normal maintenance action can inadvertently change the hardening scheme without alerting the system operator of an EMP malfunction.

2) EMP protection devices degrade from natural causes such as lightning and manmade EMI. However, this degradation is normally not noticeable to the communications' systems operator.

3) Degradation of EMP protection devices are frequency sensitive and may not be detected by the use of conventional D-C test equipment.

The paper will discuss laboratory and empirical field test data that support the concept of EMP hardness assuredness testing. Field results illustrate degradation of fielded EMP hardened systems when exposed to lightning and other transient data. Also, various test methods for EMP hardness and assuredness are discussed and trade offs provided for commercial D-C test equipment, high energy pulsers and portable low energy pulsers. An in-depth presentation will also provide information on field test experience of the survivability of a test set. Actual field tests demonstrate that commercial test equipment taken into the field will not survive the rigors of field use, unless designed to withstand a military range of environmental conditions. Empirical data of two years of experience will be presented on what to expect when doing field level testing at the pin level.

In summary, a number of government regulations require EMP hardness and assuredness programs for fielded systems. There are various test schemes for meeting the criteria and this paper presents one method being used on some programs and associated trade offs.

AN AUTOMATED MULTI-PIN TEST SYSTEM FOR DIRECT PIN-DRIVE TESTING

A.J. Bonham
Michael E. Gruchalla

EG&G Washington Analytical Services Center, Inc.
P.O. Box 9100
Albuquerque, NM 87119
Telephone No. (505) 243-2233

ABSTRACT

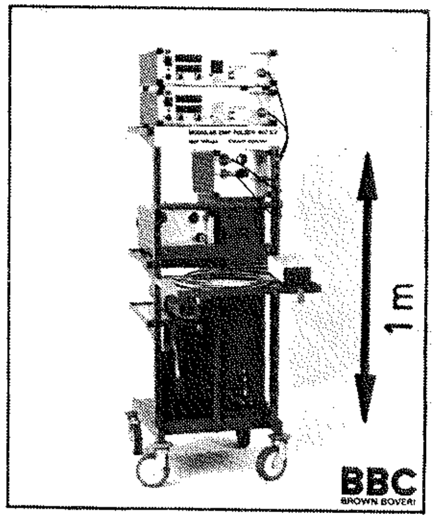
A fully automated test system is described which provides the capability of direct pin injection of true damped-sinusoidal waveforms directly into the individual pins of system elements for assessment of upset and damage vulnerability to pulsed EMP and EMP environments. The value is programmable over the range of 0.5 to 20,000 with a minimum resolution of 0.01 Q steps and the characteristic frequency over the range of 128 dB in 0.1 dB steps. Under totally automated control, up to 750 pins may be tested in a single test session. Automation is effected over the IEEE-488 bus for maximum versatility. The system control unit automatically executes the programmed test sequence for each pin, providing any available combination of Q, frequency and level for each test pulse. Drive level is dynamically controlled to prevent overtest but to minimize the number of pulses requird to achieve a specified level. Peak levels of both applied potential and current for all test pulses are recorded in the test archives. The automated test system described provides the means of a cost-effective program of 100 percent testing of all elements of a total system as one step in assuring the successful system performance in the electromagnetic environment of the intended application.

A Modular EMP Pulser System and Data Aquisition Unit For Transient Field Generation and Current Injection

D. Koenigstein, D. Hansen, H. Schaer
ASEA BROWN BOVERI Corporate Research
5405 Baden-Daettwil / Switzerland

Theoretical system analyses of possible threat levels to electronic components and systems under NEMP and other electromagnetic stress conditions predict a broad variety of possible current and voltage shapes and amplitudes. The pulse shapes range from double exponentials with ns risetimes to oscillating currents in the kHz range. Amplitudes may reach tens of kA [1].
Very fast fields can be applied to a limited test volume (Box Level Testing) using the novel GTEM cell (Gigahertz-TEM) [2] if the pulse source is fast enough. On the other hand direct current injection is used to drive the predicted currents into larger systems. A pulser family has been developed to cover this range of applications with the following features:

- 100 kV for dielectric breakdown simulation and high current drive
- Compact and portable design
- Stored energies from 1 to 1750 J
- Risetimes down to 1.5 ns into 50 Ohms
- Shortcircuit frequencies up to 100 MHz
- Currents up to 80 kA
- Easy laboratory and outdoor handling
- Fail / EMI-safe pneumatic control



To cover the desired range of currents and voltages, a portable data aquisition system for 'single shot' measurements was created, consisting of three different digitizers and a compact but powerful computer. It enables the user to measure a signal with three different sample rates in the front, intermediate and tail sections. For example, a fast rising pulse creating a dielectric breakdown and an oscillating follow current of any duration can be measured with a minimum sampling time interval of 10 ps in the front section and more than 50 000 digitized values in the remaining time window. The computer allows full signal processing like:

- automatic scaling and error correction
- signal integration and processing
- fourier analysis
- signal storage and documentation
- operator guided graphics

The system is mobile and versatile. Among other applications the system has proven to be very reliable and effective while NEMP testing an electromechanical locomotive.

References

[1] D. Hansen, "A New EMP-Generator for Direct Injection", ASEA BROWN BOVERI Publication 8706-5001
[2] D. Koenigstein, D. Hansen, "A New Family of 50 Ohm TEM-Cells with Enlarged Bandwith and Optimized Working Volume", 7th Symposium and Technical Exhibition on EMC, Zurich, March 1987

SLEET - FOUNDATION FOR ADVANCED ANALYSIS

M.E. Butler, F.C. McCloskey, M.P. Walker

TRW
Albuquerque Engineering Office
2340 Alamo SE, Suite 200
Albuquerque, NM 87106

SLEET (System Level Evaluation of Electromagnetic Tests) is an IMS (Information Management System) developed by TRW for the AFWL (Air Force Weapons Laboratory) to manage EMP data. Sleet features a data archive consisting of high level pulse, direct drive, and localized CW data records efficiently accessed through a menu-driven user interface. This paper briefly describes the SLEET development cycle and the system structure, and then details the current analysis capabilities. Finally, an overview of the long range analysis capabilities is provided.

SLEET has been developed in phases and has emphasized an interactive communication process with the EMP community throughout its development. A broadly inclusive "standard" set of data elements have been defined to support a broad range of analysis activities. The system began with system level pulse data and has recently been expanded to accommodate direct drive and localized CW data. SLEET is being used in support of the B-1B test program and development continues under AFWL's EMPDAT program.

SLEET has a flexible structure that accommodates data from a variety of sources. Standard SLEET archive file formats have been defined and input and output translators interface between SLEET and the various acquisition/processing systems currently in use by the EMP community. SLEET consists of the archived response files, relational files containing data elements describing the response, the test object and the test conditions, a menu-driven interface and applications program.

Currently, SLEET supports analysis applications including identification of "hot" zones, graphic display of response distributions, calculation of individualized safety margins, pulser amplitude variations and others. Presently under development for the B-1B program is a norms correlation matrix application which will compare norms from pulse and direct drive data to bulk cable current specifications.

SLEET provides a standardized, documented storage/retrieval methodology which makes analysis of large quantities of data practicable.

RESPONSES OF FIVE HAMS SENSOR/DRIVERS

R. H. St. John and E. A. Callan
Mission Research Corporation
1720 Randolph Road, SE.
Albuquerque, NM 87106

A Hardness Assurance Monitoring System (HAMS) is composed of a set of transmitters and receivers separated by one or more electromagnetic shielding layers. By investigating the relationship between the attenuation of the signal from the HAMS transmitters to the outside of the shield room to the receivers on the inside, leaks in the shield can be detected and characterized, and possible threat responses can be assessed.

A wide variety of sensor/driver configurations exist. In this paper, five sensor types were chosen and their responses compared for leaks of varying length and thickness. The sensor types were chosen to excite the leaks by creating a surface current either parallel or perpendicular to the major axis of the fault.

SESSION 3B

INTERACTION: CABLE SHIELDS AND CONNECTORS

Chairman: D. Hansen, BBC Brown Boveri Ltd., Switzerland

Tuesday, 17 May (morning) Building A, Conference Room B

1 8:30 **EM Coupling to Shielded Cables, Revisited**, D. C. Agouridis, Oak Ridge National Laboratory, Oak Ridge, TN

2 8:50 **Cable Response to an EMP: Comparison Between Calculations and Simulations**, M. Ianoz, Swiss Federal Institute of Technology, Lausanne, Switzerland; F. M. Tesche, LuTech, Inc., Lafayette, CA

3 9:10 **EMP Hardness Maintenance / Hardness Surveillance Considerations and Solutions for Shielded Cables**, P. J. Miller, TRW, Albuquerque, NM; W. Prather, AFWL, Kirtland AFB, Albuquerque, NM

4 9:30 **A Test Fixture for Quickly Measuring Surface Transfer Impedance of Cables**, L. O. Hoeft and J. S. Hofstra, BDM, Albuiquerque, NM

5 9:50 **Comparison of the Transfer Impedance of New Versus Fielded Tactical Army Cables**, L. Jones and B. Wyshak, SAIC, Nashua, NH

10:10 Coffee Break

6 10:40 **Measured Surface Transfer Impedance of Ferromagnetic Pipes and Conduits**, C. H. Hoeft, Albuquerque, NM

7 11:00 **Experimental Evidence for Porpoising Coupling and Optimization in Braided Cables**, L. O. Hoeft and J. S. Hofstra, BDM Corp., NM; R. Peel, Martin Marietta Astronautics, Denver, CO

8 11:20 **Electromagnetic Coupling in EMI Connector / Backshell / Braid Termination Assemblies**, L. O. Hoeft and J. S. Hofstra, BDM Corporation, Albuquerque, NM

EM COUPLING TO SHIELDED CABLES, REVISITED

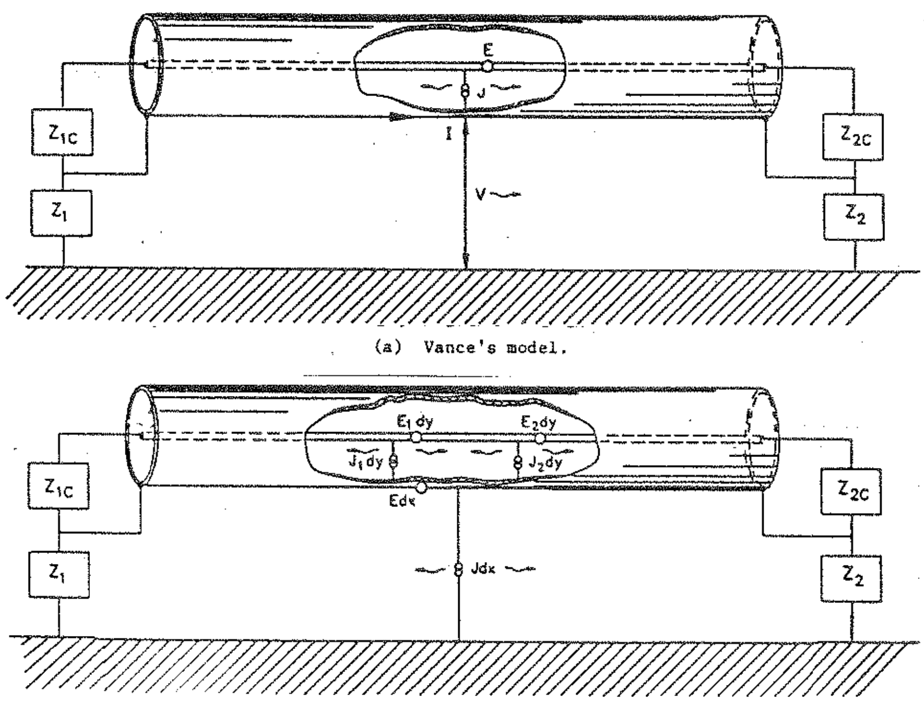
Dr. D. C. Agouridis
Instrumentation and Controls Division*

ABSTRACT

Electromagnetic coupling to shielded cables is analyzed in terms of two coupled transmission lines excited by distributed sources. Transient waveforms are reported from EMP coupling on an overhead RG-58 cable.

E. F. Vance (Coupling to Shielding Cables, Wiley, New York, 1978) describes the problem of coupling to shielded cables and assumes, as prime cause, voltage, V, and current, I, in the shield (Fig. 1a). Coupling to the core conductor occurs via the transfer impedance Z_T and admittance Y_T. The final solution results in two propagating waves on the inner line.

In the new model, Fig. 1b, distributed sources Edx and Jdx are induced on the shield by the EM wave, with the following consequences: (1) Edx and Jdx launch two propagating waves on the outer line; (2) these waves, in turn, induce distributed sources (via Z_T and Y_T coupling) in the inner line, which, in turn, launch four propagating waves on the inner line; and (3) the total voltage and current in the inner line are found by integrating the response of Edx and Jdx over the length of the line.



(a) Vance's model.

(b) New model.

FIG. 1. EM COUPLING ON SHIELDED CABLE.

*Oak Ridge National Laboratory (Oak Ridge, Tennessee 37831), Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under Contract No. DE-AC05-84OR21400.

CABLE RESPONSE TO AN EMP : COMPARISON BETWEEN CALCULATIONS AND SIMULATIONS*)

M. Ianoz and F.M. Tesche) , Swiss Federal Institute of Technology from Lausanne , Switzerland.**

Very few data if any are available showing comparisons between calculations and measurements pertaining to shielded cable response to an EMP. In order to validate numerical calculations, measurements of currents and voltages induced by a simulator have been performed. For the computations, codes previously reported [1,2] and based on the transmission line approximation have been used. The soil parameters and the electromagnetic field components used for calculation were determined by measurements.

The simulation was performed using the MEMPS (Mobile EMP Simulator) of the NC Laboratory from Spiez. Samples of 10 m length cables terminated by shielded boxes were placed under the simulator and the current in the shield as well as the current in the internal conductor were measured using current probes. The transfer impedance of the cable was measured on samples in the laboratory of the Swiss Federal Institute of Technology from Lausanne.

The comparison shows a good agreement between measured and calculated currents in the cable shield. Concerning the internal current the disagreement is much larger due to difficulties to measure the transfer impedance at high frequencies.

The authors are indepted to Mr. B. Brändli, B. Reusser and R. Steck from the NC Laboratory from Spiez who performed the measurements with the simulator and to Mr. Ph. Allenbach from the Swiss Federal Institute of Technology who performed computer calculations and the transfer impedance measurements.

[1] Tesche F.M. and T.K. Liu, "Field Exitation of Multiconductor Transmission Lines",AFWL EMP Interaction Note 351, Sept. 1978.
[2] M. Aguet, M. Ianovici, C.C. Lin, "Transient Electromagnetic Field Coupling to Long Shielded Cables", IEEE Trans. on EMC,EMC-22,1980.
*) this work was sponsored by the NC Laboratory,Spiez,Switzerland
**) LuTech, Inc., Lafayette, CA, USA

EMP HARDNESS MAINTENANCE/HARDNESS SURVEILLANCE
CONSIDERATIONS AND SOLUTIONS FOR SHIELDED CABLES

P.J. Miller

TRW Defense Systems Group
Albuquerque, New Mexico 87106

W. Prather

Kirtland Air Force Weapons Laboratory
Albuquerque, New Mexico 87117

Shielded Cables have become an essential part of the EMP protection on most systems. In spite of this fact, there are no hardness maintenance/hardness surveillance (HM/HS) programs in place today which monitor the integrity of cable shields. Couple this with the discovery that cable shields are subject to severe degradations under the normal operation of fielded systems and the problem is clear.

This paper presents data on cable shield performance taken with a simple tool called the shielded cable tester (SCT). The SCT was used to measure the transfer impedance of cable shields on various operational systems over the past year. The data will be summarized, and common problems in cable shields will be discussed. Also, lessons learned relative to the test procedure and system configurations will be addressed. Finally, recommendations will be offered pertaining to system specifications, cable shield design, and HM/HS planning.

A TEST FIXTURE FOR QUICKLY MEASURING SURFACE TRANSFER IMPEDANCE OF CABLES

Lothar O. Hoeft and Joseph S. Hofstra
The BDM Corporation
1801 Randolph Rd., S.E.
Albuquerque, NM 87106
(505) 848-5399

Some situations, particularly those involved in the production of shielded cables with transfer impedance specifications, require that the samples be measured very rapidly. In response to this requirement, a quadraxial test fixture has been developed that allows the surface transfer impedance of a cable sample to be measured with a minimum of preparation. As in a conventional quadraxial test fixture, the sample under test is placed in two concentric troughs that form the drive and guard lines. The sample is prepared by stripping the jacket, pulling back the braid and stripping the insulation from the core conductors. The termination and measurement ends of the sample are attached to terminals located in shielded boxes located external to the test fixture. Laboratory measurements demonstrate that this fixture is capable of making measurements up to 50 to 100 MHz that are as accurate as those made using a conventional quadraxial fixture. Its principal limitation is that fixture crosstalk limits the minimum transfer impedance that can be measured. Measurements indicate that the minimum transfer resistance that can be measured is .5 milliohms/meter and the minimum transfer mutual inductance is about 6 pH/m. This test fixture is also useful for measuring the transfer impedance of multiconductor cables.

Comparison of the Transfer Impedance of New Versus Fielded Tactical Army Cables

Llewellyn Jones and Bruce Wyshak

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
61 Spit Brook Road, Suite 204
Nashua, NH 03060

A major concern in hardening tactical systems is the effect of degradation of cable shields which are relied on to mitigate the coupled EMP environments. Tactical cables are handled many times and used in a physical environment that can cause the cable shield to degrade. The transfer impedance of representative cable assemblies have been measured comparing off the shelf cable assemblies with ones that have been used in the field. The transfer impedance of these cable assemblies are compared with potential degradation areas detailed.

This work supported by Harry Diamond Laboratories under Contract DAAL02-86-D-0041.

MEASURED SURFACE TRANSFER IMPEDANCE OF FERROMAGNETIC PIPES AND CONDUITS

Chistine M. Hoeft
9013 Haines Ave. NE
Albuquerque, NM 87112
(505) 298-2065

The surface transfer impedance of ferromagnetic pipes and thin-walled conduits was measured from 5 Hz to 1 MHz using triaxial and quadraxial test fixtures and a computer controlled network analyzer. The frequency dependence of the relative permeability of ferromagnetic materials was determined by measuring the surface transfer impedance of samples made of ferromagnetic (black iron water pipe and thin-walled electrical conduit) and non-ferromagnetic (copper water pipe) materials using samples of similiar dimensions.

A 22 mm (7/8 in) diameter copper pipe with a wall thickness of 1.6 mm (1/16 in) had a transfer resistance of less than a milliohm/meter and a diffusion break frequency of less than 10 kHz. A corresponding rigid thin-walled steel conduit has a slightly higher transfer resistance (a few milliohms/meter) but a much lower diffusion break frequency (a few hundred Hz). Black iron water pipe (33 mm diameter, 3.34 mm wall thickness) had a lower resistance and diffusion break frequency because of the increased wall thickness. The frequency dependence of the permeability was determined by comparing the scaled copper data to the data obtained from ferromagnetic samples. The permeability of all the ferromagnetic samples displayed some frequency dependence, however, this was not great enough to cause an increase in the surface transfer impedance at high frequencies.

The surface transfer impedance of fittings used to join thin-walled electrical conduit was also measured. When relatively new, the compression joint fittings used to join the sections of thin-walled steel conduit displayed a very low transfer impedance, being equivalent to a very short section of conduit. The surface transfer impedance of joint fittings using set screws increased as the square root of frequency, suggesting that its performance was limited by contact impedance. Above a kHz, the set screw fitting was significantly worse than the compression fitting. Both could be expected to degrade with time.

EXPERIMENTAL EVIDENCE FOR PORPOISING COUPLING AND OPTIMIZATION IN BRAIDED CABLES

Lothar O. Hoeft, Joseph S. Hofstra
The BDM Corporation
1801 Randolph Rd., S.E.
Albuquerque, NM 87106
(505) 848-5399

and

Roger Peel
Martin Marietta Astronautics Group
P.O. Box 179
Denver, CO 80207
(303) 971-6422

At high frequencies, electromagnetic energy couples through braided cable shields by two mechanisms--apertures and porpoising coupling. In a braided cable shield, the bundles of wires or carriers are alternately on the outside and inside of the shield. Porpoising coupling is the result of the finite contact impedance between the carriers which allows some of the external shield current to remain on the carriers when these wires are on the inside surface of the shield. Both aperture and porpoising coupling manifest themselves as a transfer impedance that acts like a mutual inductance. Theory predicts that aperture coupling and porpoising coupling should be opposite in phase. The magnitude and phase of a set of cable samples, chosen to provide examples of both aperture and porpoising coupling, was measured in a quadraxial test fixture. These measurements showed the predicted phase relationships. Optimized braid results when the shield construction is adjusted so that the aperture and porpoising contributions are approximately equal. Since these constributions are of opposite sign, they cancel one another.

ELECTROMAGNETIC COUPLING IN EMI CONNECTOR/BACKSHELL/BRAID TERMINATION ASSEMBLIES

Lothar O. Hoeft and J. S. Hofstra
The BDM Corporation
1801 Randolph Rd, S.E.
Albuquerque, NM 87106
(505) 848-5399

An EMI shielded cable assembly is more than shielded cable and connectors. The backshell has interfaces with both the connector and the cable shield. The interface between the connector and the backshell is usually threaded and constructed in accordance with the appropriate military standard. The interface between the backshell and the cable shield, usually metallic braid, can take on many forms, being limited only by the imagination of the backshell designer.

Previous measurements have shown that a typical backshell/braid interface, like a dual cone assembly, has a surface transfer resistance of about .1 milliohm and a transfer mutual inductance of 10 pH. Transfer impedance measurements of samples, specially constructed to determine the contribution of the threaded connector/backshell interface to the transfer impedance of the overall assembly, showed that the connector/backshell interface typically has a transfer resistance of .2 to .4 milliohms and usually has no transfer mutual inductance. That is, there is no evidence of aperture coupling. The high frequency measurements show some deviation from that expected of a solid cylindrical shield. This response appears to be due to contact impedance rather than aperture coupling.

The surface transfer impedance of the connector backshell interface was inversely proportional to the assembly torque. This was particularly evident at the higher frequencies. Torques in the range of 200 inch-pounds were required to achieve optimum performance in some cases.

Comparison of these measurements with those from a complete high quality connector/backshell/braid termination shows that the plug/receptacle interface should have a low frequency transfer resistance contribution about the same as the backshell barrel. Its high frequency response, which is roughly proportional to the square root of frequency, appears to be due to contact impedance or resistance of the spring fingers rather than aperture coupling. This is consistent with theory which predicts that the contribution of the apertures between the spring fingers is negligible because of the below cutoff attenuation of the waveguide formed by the plug and receptacle barrels.

SESSION 3C
SENSORS AND INSTRUMENTATION: APERTURE LEAKAGE MEASUREMENT SYSTEMS

Chairman: L. Libelo, Harry Diamonds Laboratories, Adelphi, MD
Tuesday, 17 May (morning) Building I, Room S109

1 8:30 **Monitor for Integrity of Seams in a Shield Enclosure**, C. E. Baum, AFWL, Kirtland AFB, Albuquerque, NM

2 8:50 **Design Considerations for a Localized Aperture Tester**, C. D. Taylor and W. D. Prather, AFWL, NM; F. Marcum, Ohio University, Athens, OH; C. C. Herrmann, TRW, Albuquerque, NM

3 9:10 **A Portable Stripline Antenna System**, C. C. Herrman, K. H. Coonrod, TRW, Albuquerque, NM; C. Taylor, Ohio University, Athens, OH

4 9:30 **An Improved Electromagnetic Leak Detection System for Shielded Enclosures**, M. K. McInerney, R. G. McCormack, U.S. Army Construction Engineering Research Laboratory, Champaign, IL

9:50 Coffee Break

5 10:20 **The Application of RFI Leak Detection Systems to Tactical Shelter HEMP Shielding Effectiveness**, J. R. Elliott, D. Keller, S. Pawelka, and J. Bowers, Electro Magnetic Applications, Inc., Lakewood, CO

6 10:40 **Development of Leak Detector Techniques for Aircraft Hardness Surveillance**, L. O. Hoeft, T. M. Salas, and J. S. Hofstra, The BDM Corporation, Albuquerque, NM; W. D. Prather, AFWL (NTAA), Kirtland AFB, NM

MONITOR FOR INTEGRITY OF SEAMS IN A SHIELD ENCLOSURE

C. E. Baum
Air Force Weapons Laboratory
Kirtland AFB
Albuquerque, New Mexico 87117-6008

This note considers a new concept for measuring the performance of shield enclosures. It allows for the presence of aperture-like faults at unknown positions over the shield enclosure. The aperture penetration is measured in a manner appropriate to bounding the response of internal equipment. The technique leads to the location of the faults as well.

DESIGN CONSIDERATIONS FOR A LOCALIZED APERTURE TESTER

Clayborne D. Taylor
William D. Prather
Air Force Weapons Laboratory

Frank Marcum
Ohio University

Carl C. Herrmann
TRW

ABSTRACT

The degradation of shielding that results from aperture perforation can be determined by using the illumination from local transmission line drivers. Moreover this type of testing can be used for hardening surveillance. From practical considerations a lossy parallel plate transmission line illuminator is found to be the most convenient test configuration, where one plate has a hole that is large enough to illuminate the aperture being tested. Using the results from numerical studies, design formulas have been developed that will enable the test engineer to design a configuration to quantitate the flux leakage through particular apertures of interest.

Transfer functions for the parallel plate transmission line aperture tester are presented for a 50 Ohm source impedance and a 50 Ohm load impedance on the transmission line and for a resistively loaded sense-wire behind the aperture. These formulas are applicable for a test configuration ultilizing a network analyzer and a current probe to monitor the excitation of the sense wire.

A PORTABLE STRIPLINE ANTENNA SYSTEM

C.C. Herrmann
K.H. Coonrod

TRW Defense Systems Group
Albuquerque, New Mexico 87106

C. Taylor

Ohio University
Athens, Ohio

A flexible, light weight stripline antenna system has been developed under the EMPTAC contract with the Air Force Weapons Laboratory. The system will be used in various Hardness Maintenance/Hardness Surveillance (HM/HS) programs. The stripline antenna is used in a low level continuous wave (CW) measurement to both induce and measure the localized current on the exterior surface of the aircraft. The antenna has no direct electrical contact to the aircraft under test, therefore it can be used to test any aperture on flight line aircraft without damage to the painted surface. The antenna system was evaluated by driving various apertures with a standard 50 ohm stripline antenna and comparing the results obtained to those obtained with the new system driving the same apertures. The electrical fields generated by the system have be modeled using a finite difference code. The evaluation results will be presented and various uses of the system will be discussed.

An Improved Electromagnetic Leak Detection System for Shielded Enclosures*

Michael K. McInerney
Ray G. McCormack
U.S. Army Construction Engineering Research Laboratory
P.O. Box 4005
Champaign IL 61820-1305

A method for quickly evaluating the electromagnetic (EM) leakage of shielded enclosures is the "sniffer" method (Lockwood: 1967). In this technique a low frequency (95 kHz) current is injected onto the enclosure skin at diagonally opposite corners. An enclosure skin or seam defect which creates a discontinuity in the current will cause parallel electric and perpendicular magnetic fields to be established at the enclosure surface. An inductive probe/receiver combination is used to "sniff" the perpendicular component of the magnetic field at the enclosure surface. A value of magnetic field strength which is much greater than the values for the surrounding skin area indicates an enclosure defect.

Because it is possible for a defect to be oriented such that it cannot be detected for certain excitation diagonals (e.g. when the injected current flows parallel to the major axis of the defect), it is necessary to use at least two sets of enclosure diagonals as excitation sources. Since present leak detectors can excite only one diagonal at a time it is necessary to make a separate pass of the receiver over the enclosure for each excitation diagonal.

The improved leak detector has the capability to repeatedly excite four diagonals sequentially. The transmitter electronically cycles through four diagonals with a programmable repetition rate. The circuit uses standard CMOS and TTL logic elements. HEXFETs are used for the high current drivers.

Tests have been conducted to determine the correlation between improved leak detector measurements and MIL-STD-285 shielding effectiveness measurements. The variability of MIL-STD-285 measurements precludes assigning a specific conversion factor between leak detector intensity and shielding effectiveness.

Lockwood (1967) attempted to correlate the sniffer with 400 MHz and 1 GHz MIL-STD-285 shielding effectiveness data. He also found that conventional MIL-STD-285 tests were inconsistent. He developed correlation curves by using modified free field tests.

References

Lockwood, R. O. (1967), "New Technique for the Determination of the Integrity of Shielding Enclosures by the Measurement of the Perpendicular Magnetic Field", 1967 IEEE Electromagnetic Compatibility Symposium Record, July 1967.

*Project sponsored by U.S.A.F. Hanscom, Electronic Systems Division.

The Application of RFI Leak Detection Systems to Tactical Shelter HEMP Shielding Effectiveness

James R. Elliott, David Keller,
Scott Pawelka, James Bowers
Electro Magnetic Applications, Inc.
12567 W. Cedar Drive, Suite 250
Lakewood, Colorado 80228

The establishment of a precise quantitative correlation between RFCW Shielding Effectiveness (SE) and HEMP SE would greatly facilitate procedure for determining the initial and the long term HEMP hardness of a shielded enclosure. To be useful, this RFCW SE must be obtainable in a reliable, cost effective and timely manner.

To explore this approach, a survey was made of commercially available Shielded Enclosure Leak Detection Systems (SELDS), RF sniffers and hand held field strength meters. Sensitivity and frequency coverage were used as criteria in selecting units for evaluation. The selected equipment was examined for repeatability of results, ease of use, reliability and overall appropriateness to the task.

The definition of SE involved the ratio of external fields to internal fields in a given shelter situation. The same leak detection equipment, with appropriate probes, was used to measure both of these quantities. For comparison purposes, additional MIL-STD-285 measurements were made on the same shelter.

Extensive numerical modeling of RFCW and HEMP excitation was used to establish the correspondence between measurements in both cases. Seam transfer impedance (a quantity intrinsic to the shelter and independent of the nature of the EM excitation) was used in all cases to link the external environment to the fields penetrating to interior.

To validate this application of RFCW leak detection equipment, a series of measurements was made at the Harry Diamond Laboratories EMP simulator AESOP. In general, the AESOP values are predictable from the combination of RFCW measurements and modeling results. Measurements and comparisons are presented with overall conclusions about the efficacy of the approach.

DEVELOPMENT OF LEAK DETECTOR TECHNIQUES FOR AIRCRAFT HARDNESS SURVEILLANCE

L. O. Hoeft, T. M. Salas, and J. S. Hofstra
The BDM Corporation, 1801 Randolph Rd, SE, Albuquerque, NM 87106,

William D. Prather
Air Force Weapons Laboratory (NTAA), Kirtland Air Force Base, NM 87117

Three electromagnetic leak detectors (2 VLF and 1 UHF) have been evaluated as hardness surveillance tools. The electromagnetic characteristics of the leak detectors were measured, their performance was determined in the laboratory using a set of calibrated apertures and they were used to measure the shielding effectiveness of hardened and unhardened apertures on a large commercial aircraft. These measurements showed that the low frequency measurements were more stable than the high frequency measurements, but the measurement frequency was somewhat low for aircraft hardness survelllance since it was about a decade below the fundamental resonance of typical aircraft. The UHF measurements were quite variable and did not inspire confidence, especially for evaluating aperture sizes found on aircraft. Skin current excitation was more convenient than localized field excitation because it simpler (the excitation source did not have to be moved for different measurement locations) and it was easier to excite and find all the "EM hot spots." The EM leak detector measurements were consistent with theory, thereby demonstrating that they could be used in a quantitative manner. Finally, the battery operated instruments were much more useful and convenient than the A.C. operated instruments.

An effort to extend leak detector procedures to frequencies above a MHz led to the development of a new technique called SPEHS (Single Point Excitation for Hardness Surveillance) that electromagnetically excites the aircraft and produces surface magnetic and electric field distributions that are similar to those that result from exposure to plane waves. The aircraft is driven at the intersection of the wings and the fuselage at one of the plane's resonant frequencies. Surface magnetic fields in the range of 1 to 10 mA/m are easily produced. Measurement of the magnetic field at a prescribed distance from the outside and inside surface of hardened apertures, such as window screens and gasketed doors, using a small loop and a battery operated field strength meter allows the shielding effectiveness of these hardening elements to be determined. When a current probe is substituted for the loop, this technique can also be used to characterize conductive penetrations.

The SPEHS technique is a meaningful hardness surveillance tool capable of quickly characterizing an aircraft's shielding elements to within a factor of two (6 dB), and determining where the most significant "hot spots" are.

SESSIONS 4A and URSI E-1
ENVIRONMENTS

Chairman: Col. J. Justice, Air Force Weapon Laboratory, NM
Tuesday, 17 May (afternoon) Building I, Auditorium

1 1:30 **Integral Formulation of Early-Time HEMP Theory**, W. J. Karzas, Metatech Corporation, Los Angeles, CA

2 1:50 **Parameter Studies of Early-Time High-Altitude EMP Fields**, K. D. Leuthauser, Fraunhofer-Institut für Naturwissenschaftlich-Technische Trendanalysen (INT), Germany

3 2:10 **Distortions in High-Altitude EMP Footpoints**, C. H. Vittitoe, Sandia National Laboratories, Albuquerque, NM

4 2:30 **Computation of Ground Magnetic Signal due to Magnetohydrodynamic EMP**, S. P. Auerbach and S. W. McDonald, Berkeley Research Associates, Berkeley, CA

2:50 Coffee Break

5 3:20 **Experimental Study of the Connection Between a Conductive Structure and an Electrical Discharge**, G. Labaune, A. Bondiou, J. Alliot, F. Morillon, and B. Hutzler, France

6 3:40 **The Lightning Stepped Leader - A Tortuous Path Model**, S. P. D. R. Nathan, Petaling Jaya, Malaysia ; K. Arichandran, University of Malaya, Kuala Lumpur, Malaysia

7 4:00 **Propagation of HEMP Under Ground**, Z. Bihua, Nanjing Engineering Institute, Nanjing, China

Integral Formulation of Early-Time HEMP Theory*

by

William J. Karzas

Metatech Corporation
13101 Washington Boulevard, Suite 207
Los Angeles, CA 90066-5125

The published presentations of the theory for calculating the early-time high altitude electromagnetic pulse (HEMP) have been in differential form. While this form is most amenable to computation, it does not provide a great deal of physical insight, nor is it easy to estimate the accuracy of the resulting approximation.

In this paper we present an integral formulation based on the Green's function solution to Maxwell's equations with the high altitude source currents. A clearer physical picture is given of which parts of the source-region space contribute to the signal at the observer at each retarded time.Some simple manipulation of the integrals shows explicitly which terms can be collapsed into the classic early-time ("high-frequency") line integral approximation, and which terms are omitted.

Estimating the magnitude of these omitted terms relative to that of the retained term provides an answer to the question of for what length of retarded time the calculation is valid. Rather surprisingly, it can be shown that the range of validity is some tens of microseconds.

*Research performed under DNA001-85-C-0125

Parameter Studies of Early-Time High-Altitude EMP Fields

K.-D. Leuthäuser
Fraunhofer-Institut für Naturwissenschaftlich-Technische Trendanalysen (INT)
Appelsgarten 2
5350 Euskirchen, Germany

ABSTRACT

EMP interaction studies normally rely on a single worst case standard waveform which neither reflects the influence of particular nuclear weapon parameters nor the spatial variation of EMP environment on ground. Therefore, such waveforms may not be appropriate for EMP interaction with spatially extended networks, e.g. power systems.

A high-altitude EMP code has been developed which takes into account the exact angle/energy correlation of Compton electrons and their equation of motion in the earth magnetic field while slowing down due to ionization loss. Total Compton currents and air conductivities are calculated by averaging over Compton electron energies and azimuth angles.

Maxwell's equation are solved in retarded time and high-frequency approximation[1]. Feed-back of the calculated EMP fields is only considered with regard to the E-field dependency of the electron mobility, whereas their influence on the equation of motion of the Compton electrons has been neglected (non self-consistent model).

Extensive parameter studies include a variety of gamma pulse shapes with different rise and decay time constants (e.g., delta function, unit-step with exponential decay, reciprocal of the sum of two exponentials), variation of mean energy of source gammas and total gamma yield of the nuclear weapon as well as variation of height of burst and observer location with regard to Ground Zero.

Comparison with recent CHAP code calculations[2] shows fairly good agreement.

---

1) W.J. Karzas and R. Latter, "Detection of the Electromagnetic Radiation from Nuclear Explosions in Space", Phys. Rev. 137, B 1369 (1965)

2) C.L. Longmire, R.M. Hamilton, J.M. Hahn, "A Nominal Set of High-Altitude EMP-Environments", ORNL/Sub/86-18417/1 (1987)

Early-Time HEMP - Sample Calculations

from a Simplified Gamma Source*

by

William A. Radasky
William J. Karzas
Christopher W. Jones

Metatech Corporation
358 S. Fairview Avenue, Suite E
Goleta, CA 93117

In order to design electronic systems to withstand the electrical stresses induced by high-altitude EMP (HEMP) and to test systems to ensure that they have been properly hardened, one must establish a design criterion which in the case of HEMP has historically taken the form of an environment waveform. This paper is intended to review the basic HEMP environment theory, modern calculational methods and a sample of results covering the first microsecond of the signal (referred to as the early-time HEMP). In addition the variability of calculated HEMP waveforms with important parameters is described.

The objective of this paper is to try to correct misconceptions that have been created recently in widely distributed papers published in the popular press. A second major point of this paper will be to indicate that while HEMP waveforms are variable within some bounds, there are saturation limits which can be used to develop a simplified system design waveform. A sample early-time HEMP waveform based on unclassified sources is developed and presented in this paper.

*Research performed under DNA001-85-C-0125

Distortions in High-Altitude EMP Footprints

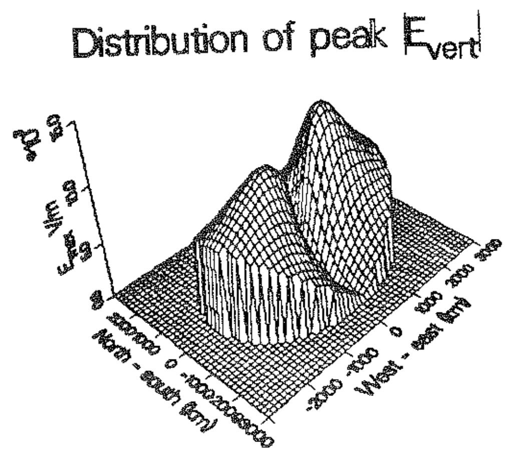
Charles N. Vittitoe, 2322
Sandia National Laboratories
P O Box 5800
Albuquerque, New Mexico 87185

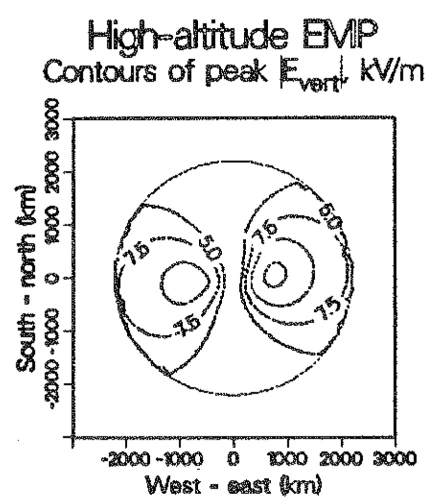
for presentation at the
1988 NEM EMP meeting
SRI International, Menlo Park, CA
16-20 May 1988

The peak values of the EMP produced by a nuclear explosion above ~30-km altitude and incident on the earth's surface are often collected into footprints (contour diagrams of constant electric field strengths, or "smile" diagrams) as one indication of the EMP threat. These diagrams may be generated by models of the dominant magnetic-dipole term that exhibits a basic east-west asymmetry (symmetry) in the electric field's vertical component (absolute value). As Longmire discovered in his early work with the CHAP code and more recently emphasized in a numerical fit to some CHAP results,[1] the next term in a perturbation treatment of the phenomena is the electric-quadrupole signal created by the transverse current densities (rather than the radial densities) interacting with the geomagnetic fields. This signal adds east-west and north-south distortions to the peak EMP footprint. These distortions are more pronounced in the vertical component illustrated below. (Values are truncated to zero for positions beyond the line-of-sight circle.) Further distortions occur in the mapping from a ground-range, magnetic-azimuth to a longitude, latitude coordinate system and by implementation of a more realistic geomagnetic field than the static magnetic-dipole model used in reference 1.

Rather than the peak EMP, coupling to a particular system is more likely to involve the peak of a specific component of the electric field or, perhaps, the amplitude for that component's spectral content in a particular frequency band. These distributions can be quite different from the usual smile diagrams. Illustrations have been generated from the numerical fits presented in reference 1. The fits are for a nominal large-yield burst at 400 km over the central US where the geomagnetic dip angle is near 70 degrees and where the field strength at ground zero is 0.56 gauss.[1] Some generalizations are considered.

1. C. L. Longmire, R. M. Hamilton, and J. M. Hahn, A Nominal Set of High-Altitude EMP Environments, EMP Theoretical Note 354, January 1987.





Computation of Ground Magnetic Signal due to Magnetohydrodynamic EMP;* *Steven P. Auerbach and Steven W. McDonald, Berkeley Research Associates, PO Box 241, Berkeley, CA 94701* -- As a computational model for computing the MHD EMP ground magnetic signal, we consider the linear propagation of an Alfvén wave pulse through a model ionosphere (with vertical and lateral nonuniformity) and subsequent coupling to the earth-ionosphere vacuum cavity. The pulse is propagated from high altitudes numerically using a Phase-space eikonal method, which has been shown to produce accurate results for the locally-averaged wave intensity even in the long-wavelength regime considered here. The arrival of the wave at the base of the ionosphere creates a time-dependent spatial current distribution which drives the earth-ionosphere cavity. A boundary value problem is solved for the temporal and spatial behavior of the magnetic signal on the ground, which arises due to reflection and subsequent propagation of the Alfvén wave in the ionosphere.

*Work supported by Defense Nuclear Agency

EXPERIMENTAL STUDY OF THE CONNECTION BETWEEN A CONDUCTIVE STRUCTURE AND AN ELECTRICAL DISCHARGE

by G. Labaune, A. Bondiou, J.C. Alliot
Office National d'Etudes et de Recherches Aérospatiales,
BP 72, 92322 Châtillon Cedex, France

and F. Morillon, B. Hutzler
EDF, Centre des Renardières, Moret sur Loing, France

This paper discusses various experiments whose goal is the understanding of the physical processes involved during the connection between a conductive structure and an electrical discharge.

We give experimental results recorded during the connection between an electrically floating Transall aircraft mock-up (scale 1/10th) and a 10 m electrical discharge. Typical results deal with currents, electric and magnetic fields appearing on the mock-up surface and cameragrams describing the phenomenology of the discharges propagation in both gaps.

We shall finally discuss the extrapolation of the results to a possible interpretation of the lightning aircraft attachment.

THE LIGHTNING STEPPED LEADER
- A TORTUOUS PATH MODEL

by

Subramaniam P.D.R. Nathan
Sunway College, 21, Jalan Selangor
46200, Petaling Jaya, MALAYSIA

and

Dr. K. Arichandran
Department of Electrical Engineering,
Univeristy of Malaya, 59100
Kuala Lumpur, MALAYSIA

ABSTRACT

It is a known fact that in reality the path of a lightning stepped leader is neither vertical nor straight, but takes on a tortuous geometry. This geometry is not delineated by any one agency and is due mainly to local meteorological conditions in the vicinity of the thundercloud. Using available information on the distribution of certain stepped leader parameters, like the individual step lengths and orientations, a tortuous path model of the leader was simulated in a microcomputer. The Monte-Carlo technique was employed in simulating the distribution functions of step length and orientation of a particular leader stroke.

The effects of this tortuous geometry on the resultant electric field and the leader to return stroke electric field ratio (EL/ER ratio) are presented and discussed. In the light of these effects, the discrimination between the uniform and linear charge density distribution models of the leader is shown to be difficult. All other significant effects due to the tortuosity are also presented.

PROPAGATION OF HEMP UNDERGROUND

Zhou Bihua
Nanjing Engineering Institute
1 Haifuxiang, Nanjing, China

ABSTRACT

Having a peak electric field of nearly tens of kV/m near the ground, HEMP may endanger underground electric and electronic systems. It is, therefore, necessary to estimate the strength of HEMP fields transmitted underground. The following points are dealt with in this paper.

1. According to the geographical location of China and the penetration of HEMP energy at the worst, the polarization and the angle of incidence in engineering calculations may be determined as follows:

   For horizontal polarization, the incident electric field is E_{HI} = Emax, the burst point lies to the north of the observer, and the angle of incidence $\theta_1 = I$. For vertical polarization, the incident electric field is E_{VI} = 3/4EmaxSin(90°-I), the burst point lies to the southwest or southeast and $\theta_1 = 72° \simeq 76°$. Where Emax is the peak electric field strength on the ground, I is the geomagnetic dip angle around the observer.

2. The earth is considered as a kind of semiconducting medium. when a plane wave in the air is incident upon the ground, the formula of the angle of refraction θ_2 is derived as follows:

$$\theta_2 = \mathrm{Sin}^{-1}\{\mathrm{Sin}\,\theta_1/\sqrt{1/2[\varepsilon r2 - \mathrm{Sin}^2\theta_1 + \sqrt{(\sigma_2/\omega\varepsilon o)^2 + (\varepsilon r2 - \mathrm{Sin}^2\theta_1)^2}]}\}$$

$$\approx \mathrm{Sin}^{-1}\{\mathrm{Sin}\,\theta_1/\sqrt{1/2[\varepsilon r2 + \sqrt{\sigma_2/\omega\varepsilon^2 r2}]}\}$$

   where θ_1, θ_2 are the respective angles of incidence and refraction, εo is the permittivity of free space, εr2 , σ_2 are the relative permittivity and electrical conductivity of the ground. Several angles of refraction have been worked out with the substitution of typical parameters.

3. For example, the following is the result of variations of energy density spectrum of transmitted HEMP obtained on the typical electrical parameters of the ground and the worst incident case.

   The bands in which about 95 percent HEMP energy is concentrated are: (1) when εr2 = 10, $\sigma_2 = 10^{-2}$S/m, 10^4 to 10^7 Hz for less than 10 meters in depth; 10^3 to 10^6 Hz for 20 to 50 meters; 10^2 to 10^5 Hz for 100 meters in depth. (2) When εr2 = 10, $\sigma_2 = 10^{-4}$S/m, all 10^4 to 10^7Hz for less than 100 meters in depth.

4. The time-domain waveforms of HEMP which varies with different depth is obtained by using the inversion of FFT.

   For example, when εr2 = 10, $\sigma_2 = 10^{-2}$S/m, and the depth is from 10 to 100 meters, attenuations of the peak value field varies from 44dB to 96dB, and the peak-time varies from 280 ns to 12 μs. When εr2 = 10, $\sigma_2 = 1^{-4}$S/m, the corresponding variation is from 12 dB and 150 ns to 16 dB and 1.1 μs.

SESSION 4B
INTERACTION: APERTURES

Chairman: M. Harrison, Defense Nuclear Agency, Kirtland AFB
Tuesday, 17 May (afternoon) Building A, Conference Room B

1 1:30 **Transfer Impedance Measurements of Aircraft Cables and Apertures - Pulse vs. CW**, W. D. Prather and C. D. Taylor, AFWL; P. J. Miller and C. C. Herrmann, TRW

2 1:50 **Fast-Rise EMP Coupling Characterization of Realistic POEs**, A. P. Ludwigsen and R. J. King, Lawrence Livermore National Laboratory, Livermore, CA

3 2:10 **Measured Electromagnetic Coupling Through Aircraft Windows and Doors**, L. O. Hoeft, The BDM Corporation, Albuquerque, NM; C. C. Herrmann, TRW, Albuquerque, NM; W. D. Prather, AFWL

4 2:30 **Predicted Shielding Effectiveness of Apertures in Large Enclosures as Measured by MIL-STD-285 and Other Methods**, L. O. Hoeft, T. M. Salas, and J. S. Hofstra, The BDM Corporation, W. D. Prather, AFWL, Kirtland AFB, NM

2:50 Coffee Break

5 3:20 **Finite Difference Time Domain Thin Slot Modeling and Experimental Validation**, S. T. Pennock, Lawrence Livermore Laboratory, Livermore, CA; K. S. Yee, Lockheed, Sunnyvale, CA; J. C. Kasher, University of Nebraska, Omaha, NB

6 3:40 **Parameterization of HEMP Coupling Through Apertures in Enclosures as a Function of Aperture Size, Incident Polarization and Enclosure Size**, R. A. Dalke, Electro Magnetic Applications, Inc. , Lakewood, CO

7 4:00 **Equivalent Polarizabilities of Apertures with Depth**, K. C. Chen, L. K. Warne, and T. E. Koontz, Sandia National Laboratories, NM

Transfer Impedance Measurements of Aircraft Cables and Apertures

– Pulse vs. CW –

William D. Prather
Clayborne D. Taylor
Air Force Weapons Laboratory

Paul J. Miller
Carl C. Herrmann
TRW

Abstract

The AFWL has been developing techniques for measuring the hardening elements of shielded aircraft as they are installed in the system. These techniques are extremely useful for quality control, acceptance specs, hardening verification, and hardness surveillance. One question which naturally arises is that of the comparison with time-domain response data. In order to address this question, measurements of the transfer impedance of windows, doors and shielded cables were made in the horizontally polarized dipole simulator and the results compared to the same quantities measured using localized CW techniques. The results of these comparisons are shown in this paper along with a discussion of the merits and limitations of the respective measurement techniques.

FAST-RISE EMP COUPLING CHARACTERIZATION OF REALISTIC POEs*

A. P. Ludwigsen and R. J. King
Lawrence Livermore National Laboratory
L-156
Livermore, CA 94550

ABSTRACT

The low-level cw characterizations of 13 different POE configurations in a 30x36x36 inch enclosure were measured over the 45 MHz to 18 GHz range using the LLNL EMPEROR Facility. By measuring both the amplitude and phase of the coupled cw signal over such a broad frequency range, the spectral response of an impulse incident field is essentially achieved. Then, by multiplying this impulse response by the complex spectrum of an arbitrary incident field waveform and taking the inverse Fourier transform gives the temporal response of the test configuration to that waveform. Further, by scaling the size of the test object, the temporal response to larger or smaller test objects can be predicted.

Typical results which illustrate the utility of these techniques will be given for several POEs and scaled object sizes. POEs tested include 10 and 25 cm long slots, "soft" and "hard" lapped joints, butt joints, multiconductor and single pin connectors open to the exterior, shielded coaxial and power cables which penetrate from the exterior to the interior of the enclosure, a honeycomb air vent and a waveguide below cutoff. In these studies, a 46 cm monopole was used to sense the integrated field inside the enclosure, and a current probe was used to measure the induced currents on internal wires up to 1 GHz.

* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48 and the Defense Nuclear Agency under IACRO 87-853.

MEASURED ELECTROMAGNETIC COUPLING THROUGH AIRCRAFT WINDOWS AND DOORS

Lothar O. Hoeft
The BDM Corporation
1801 Randolph Rd., S.E.
Albuquerque, NM 87106
(505) 848-5399

C. C. Herrmann
TRW Defense Systems Group
2340 Alamo S.E., Suite 200
Albuquerque, NM 87106
(505) 768-1156

William D. Prather
Air Force Weapons Laboratory (NTAA)
Kirtland AFB, NM 87117
(505) 844-0327

Many aircraft need to be modified in order to reduce the amount of electromagnetic energy this is coupled to the inside. The windows and doors are obvious coupling paths. Typical treatments for windows include the installation of screens and metal blanks. Doors are treated by replacing environmental seals with conductive gaskets. The electromagnetic coupling through the doors and windows of a large commercial aircraft was determined by measuring the open circuit voltage developed in a resistively terminated wire place across the inside of the aperture when a transverse electromagnetic (TEM) wave was injected on the outside surface of the aircraft using a special test fixture. Measurements were made with and without electromagnetic (EM) control devices installed. Window screens reduced the coupling by about 20 dB while metal window blanks with circumferential conductive gaskets were more effective (45 dB) because the gaskets provided a tighter electromagnetic seal around the edge of the windows. Conductive gaskets reduced the coupling through the cargo door by about 28 dB. The performance of a personnel door was only 10 dB due to differences in construction of the door and its latching mechanism. However, when the aircraft was pressurized, the shielding increased to 22 dB. The voltage response measurements were also used to calculate effective aperture impedances (inductance) for the untreated and treated apertures. These were consistent with their geometric dimensions. The importance of making good circumferential contact around the treatment was again demonstrated.

PREDICTED SHIELDING EFFECTIVENESS OF APERTURES IN LARGE ENCLOSURES AS MEASURED BY MIL-STD-285 AND OTHER METHODS

L. O. Hoeft, T. M. Salas, and J. S. Hofstra
The BDM Corporation
1801 Randolph Rd, SE
Albuquerque, NM 87106
(505)848-5399

William D. Prather
Air Force Weapons Laboratory (NTAA)
Kirtland Air Force Base, NM 87117
(505) 844-0327

Polarizability theory has been applied to the problem of predicting the magnetic field shielding effectiveness of a a conductive shield with a well defined aperture. Shielding effectiveness, as defined by MIL-STD-285 is the ratio of the fields at a prescribed point with and without the shield in place. Using the relationships for the polarizability of a circular aperture and the field due to a magnetic dipole, the ratio of H_{ref} (magnetic field without shield) to H_q (magnetic field with shield) becomes: $Href/H_q = 0.295\ (R/a)^3$ where a is the aperture radius and R is the distance of the recieving loop from the shield. For R = 16 in = .406 m, $Href/H_q = 19.7 \times 10^{-3}\ a^3$ and the shielding effectiveness, SE = -34 - 60 log a . For a = 1 in = .0254 m, the predicted shielding effectiveness is 61.7 dB. The shielding effectiveness of such an aperture as measured by several RF leak detectors is about 60 dB. The agreement is remarkably good.

Sometimes an alternative definition of shielding effectiveness is useful, namely, the ratio of the surface field on the external surface to the magnetic field at a prescribed distance inside of the conductive shield. The same relationships can be used to predict the shielding effectiveness of an aperture under these conditions. The resulting shielding effectiveness is: S.E. = 13.5 + 60 log R + 60 log a.

Note that in both cases, the shielding effectiveness is a strong function of the distance from the shield and thus is not an intrinsic electromagnetic parameter.

FINITE DIFFERENCE TIME DOMAIN THIN SLOT MODELING AND EXPERIMENTAL VALIDATION*

Steven T. Pennock, Kane S. Yee**, and John C. Kasher***
Lawrence Livermore National Laboratory
L-156
Livermore, CA 94550

Finite difference time domain computer codes for solving electromagnetics problems have existed for about twenty years, and have proven to be very successful. As computers and memories have become larger, the problems attempted with FDTD have become more complex. Even with today's supercomputers, however, modeling small details in a relatively large object can overwhelm the computer's capabilities, both in time and memory requirements. This has led to a search for algorithms which allow small details to be modeled, while retaining a relatively coarse grid for the rest of the object. Of particular interest in this regard are thin slots, such would be found on a missile section of airplane fuselage.

An algorithm which models such small slots has been written, based on a simple physical model, and applied to the case of a circumferential slot in a rectangular box of square cross-section. E-field values inside the box were predicted by the code, and a series of experiments were carried out, to determine the effectiveness of the code's predictions. The results of the computer runs and their comparison with experimental data will be presented, along with a brief description of the algorithm.

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

** Currently with Lockheed, Sunnyvale, CA.

*** University of Nebraska, Omaha, NB.

Parameterization of HEMP Coupling Through Apertures in Enclosures as a Function of Aperture Size, Incident Polarization and Enclosure Size

Roger A. Dalke
Electro Magnetic Applications, Inc.
12567 W. Cedar Drive, Suite 250
Lakewood, Colorado 80228

Most enclosures or shielded systems require openings such as windows, doors, ventilation openings, and access hatches. The characteristics of HEMP penetration through such apertures must be understood and quantified in order to develop appropriate hardening techniques. This report presents the results of computer modeling of electromagnetic coupling through apertures of varying sizes in a generic enclosure. The required HEMP interaction modeling is accomplished by utilizing time domain three dimensional finite difference methods. In order to minimize the time required for numerical calculations, the problem is divided into interior and exterior parts. The incident field used for exterior calculations is the standard Bell double exponential source. In accordance with the uniqueness theorem, the tangential electric fields determined from the exterior problem are utilized as boundary conditions for the interior problem. This technique allows the wire configuration within the enclosure to be altered without performing calculations over the entire problem space. This assumes that the aperture fields are not greatly sensitive to the details of the interior wiring.

The results presented compare the interior electromagnetic fields, electromagnetic energy, and coupling to wires for different aperture sizes. The coupling to a small metallic box inside of a generic enclosure is also examined. Both horizontally and vertically polarized incident fields are considered. These results suggest that a power law "rule of thumb" may be used to estimate the worst case relationship between the interior fields, aperture size and incident fields. This is an important step toward determining design criteria for HEMP hardening.

EQUIVALENT POLARIZABILITIES OF APERTURES WITH DEPTH

Kenneth C. Chen, Larry K. Warne, and Terry E. Koontz
Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185

ABSTRACT

Equivalent polarizabilities of apertures on an infinitesimally thin conducting plane have been widely used in the EMP community to treat aperture penetration problems. In practice, the conducting plane has a finite thickness. When this thickness is small compared to the length and width of the aperture, the aperture depth can be neglected. However, when the width of the aperture is comparable or even smaller than its depth, its effect can be significant. Long slots and hatch apertures can belong to this latter case. This paper uses simple arguments to derive the three principal equivalent polarizabilities of a long slot in the static limit. The results are compared to more elaborate calculations [1,2]. The antenna radius is also introduced as a key parameter for these equivalent polarizabilities [1,2]. Two simple examples are given to illustrate the use of these polarizabilities: (1) zero-order hatch aperture polarizabilities, and (2) an equivalent circuit for a wire behind a long slot aperture with depth.

References

[1] L. K. Warne, K. C. Chen, "Electromagnetic Penetration of Narrow Slot Apertures Having Depth" submitted to IEEE Transactions on Antennas and Propagations.

[2] L. K. Warne, K. C. Chen, "Relation between Equivalent Antenna Radius and Transverse Line Dipole Moments of a Narrow Slot Aperture Having Depth," submitted to IEEE Transactions on Electromagnetic Compatibility.

SESSIONS 4C and URSI E-2

HARDENING TECHNOLOGY: SPECIFICATIONS AND STANDARDS

Chairman: G. Baker, Defense Nuclear Agency, Alexandria, VA

Tuesday, 17 May (afternoon) Building I, Room S109

1 1:30 **Nuclear Survivability Awareness and Training,** Maj. R. T. Odierno, Defense Nuclear Agency, Washington, DC; J. K. Burdick and W. A. Brummer, Science & Engineering Associates, Albuquerque, NM

2 1:50 **EMP Protection Attained Through Use of a Multitier, Stress-Hardening Specification,** D. F. Peach, U.S. Department of Commerce, Boulder, CO

3 2:10 **The Importance of Practical Cable Shielding Specifications for EMP Hardened Cables,** P. J. Miller, TRW, Albuquerque, NM; W. Prather, AFWL, Albuquerque, NM

4 2:30 **Error Analysis, Bounding and Stress Upper Bound Estimation,** F. Wong and F. C. Yang, Kaman Sciences Corp., Dikewood Div., Santa Monica, CA; K. Gallegos, AFWL, Albuquerque, NM

2:50 Coffee Break

5 3:20 **Are Five Norms Better Than One? The EMPTAC Hardness Surveillance - Phase 2 Test,** R. Thomas, MRC; B. Davis and D. McLemore, Kaman Sciences Corporation

6 3:40 **Revising Specifications and Standards to Include EMP-Hardening Considerations,** J. Casper, SRI International, Menlo Park, CA

7 4:00 **Shielding Specification and Verification Based on the Generalized Shield Concept,** T. Karlsson, Swedish National Defense Research Institute (FOA), Linkoping, Sweden

8 4:20 **Improvements to MIL-STD-461C CS10 and CS11 Tests,** G. Oberto and G. Rostagno, Aeritalia, Caselle, Italy

9 4:40 **Overview of DoD-Handbook on "HAMS Planning Guidelines,"** Maj. R. T. Odierno, DNA/PRAS, Washington, DC; W. A. Brummer, Science & Engineering Associates, Inc., Albuquerque, NM

NUCLEAR SURVIVABILITY AWARENESS & TRAINING

Major Raymond T. Odierno, USA
HQ DNA/PRAS
Washington, DC, 20305-1000

Janis K. Burdick and William A. Brummer
Science & Engineering Associates, Inc.
Albuquerque, New Mexico

DNA is cataloging nuclear survivability awareness and training materials which are available within DoD and industry. Research carried out in 1987 showed that substantial material exists, and that the need for this training is great. Approximately 150 courses or materials have been identified on a broad range of specific topics such as phenomenology, radiation effects technology, and survivability for tactical systems. Courses deal with weapons systems as diverse as the Abrams Tank, Mk 21, Minuteman, etc. Efforts to identify and catalog these materials are underway, and soon a comprehensive catalog will be available. For each item, the catalog will provide information in approximately 20 catagories such as audience, topic, source, synopsis, evaluation, etc.

While the catalog will be in book form, it will also be offered on disk for the PC. The data base will incorporate a search routine to help the user easily narrow criteria to find specific information. The search process does not require that the operator have any prior knowledge of either the catalog itself or the routine. Operation is obvious and follows an intuitive, natural process for identifying courses and individual materials for building new training programs.

To make the catalog as complete as possible, input is needed from the entire defense community. DNA is soliciting information on existing training materials which relate to survivability from all nuclear threats. Participation is greatly encouraged, as this is the only means of assuring that the catalog is choate and accurate.

DNA wants the entire defense community to be aware of this project. Preliminary research identified approximately 70 unmet needs in survivability training. Although there are certain needs for which no courses exist, many more materials are available than was previously realized. This catalog will be available to assist everyone in meeting requirements for nuclear survivability awareness and training.

EMP PROTECTION ATTAINED THROUGH USE OF A MULTITIER, STRESS-HARDENING SPECIFICATION

David F. Peach
U.S. Department of Commerce
National Telecommunication and Information Administration
Institute for Telecommunication Sciences
325 Broadway ITS.N1
Boulder, CO 80303

A Multitier Hardening Specification has been developed for use in classifying or specifying long-haul fiber optic links that are used for time-critical, Government traffic. Specifically this specification is intended to contribute to the National Security and Emergency Preparedness (NSEP) readiness of the country's fiber optic telecommunication networks. Although this document is referred to as a specification, it should be used (considered) as a design guideline. The use of a stress-hardening guideline to aid in the design of commercial fiber optic telecommunication systems and their installation can be of benefit in attaining EMP protection. For example, hardening goals for EMP protection can be attained, in some cases, by maintaining consistent installation practices. The Multitier Specification presents a ranking of parameters and the levels of protection that can be expected at each level of hardness. The specification deals with all types of stress, including EMP and other nuclear effects. Several parameters influence the electromagnetic stress resistance of a fiber optic system. Each of these parameters are evaluated to determine the amount of electromagnetic attenuation or protection provided. Although the stress threat scenario is not presented, the information is presented such that system survival can be determined when the threat magnitude is defined. Based on the evaluation and the information presented, the judicious use of some simple parameters can provide significant electromagnetic protection. The application of the Multitier Specification will ensure that stress-mitigation goals are met. This paper will provide an overview of the Multitier Specification; a summary of the stress-protection goals for each level of hardness, a synopsis of the detailed background data for mitigation of nuclear effects, and a summary of an actual application of the Multitier Specification in upgrading the hardness of an existing fiber optic link.

THE IMPORTANCE OF PRACTICAL CABLE SHIELDING SPECIFICATIONS FOR EMP HARDENED CABLES

P.J. Miller

TRW Defense Systems Group
Albuquerque, New Mexico 87106

W. Prather

Kirtland Air Force Weapons Laboratory
Albuquerque, New Mexico 87117

Cable shields provide the main line of defense against EMP on most hardened systems. As such, it is imperative to validate the integrity of cable shields during the design, production, and operational phases of a system. Unfortunately, two problems stand in the way of cable shield validation:

1) Industry and government use of overly simplistic "shielding effectiveness" specifications, and

2) The lack of simple yet effective validation tools and procedures.

This paper discusses the problems inherent in the use of shielding effectiveness (SE) specifications; (a companion paper, "Evaluation of a Simple Shielded Cable Tester on Operational Systems" addresses the later issue). A comparison of actual cable performance versus the typical SE specifications levied against EMP hardened cables clearly demonstrates that the concept of SE has limited usefulness. In addition, SE specifications are often ambiguous and lead to conflicting interpretations by the cable manufacturer and the procurer. This paper will recommend specifications based on transfer impedance, that coincide with realistic expectations of cable performance. The results are specifications that can be validated during system development, production, and as part of a comprehensive hardness maintenance and surveillance program.

ERROR ANALYSIS, BOUNDING AND STRESS UPPER BOUND ESTIMATION

F. Wong
F.C. Yang

Kaman Sciences Corporation
Dikewood Division
2800 28th Street, Suite 370
Santa Monica, California 90405

K. Gallegos

Air Force Weapons Laboratory
Kirtland Air Force Base
Albuquerque, New Mexico 87117

ABSTRACT

Accurate or high confidence hardness assessment test programs include identifying and quantifying all sources of uncertainties and variations and calculating their combined effect on the threat response upper bound estimate. Systematic procedures are developed to obtain accurate bounds for various uncertainties such as extrapolation error, repeatability error and aircraft variations such as orientations and polarizations. A new technique is developed to tightly upper bound the combined effect due to these uncertainties. EMP Test Aircraft (EMPTAC) test data will be used to illustrate these techniques and the overall procedure to obtain an accurate stress upper bound estimate.

ARE FIVE NORMS BETTER THAN ONE?
THE EMPTAC HARDNESS SURVEILLANCE - PHASE 2 TEST

R. Thomas
Mission Research Corporation

B. Davis
Consultant
Kaman Sciences Corporation
Dikewood Division

D. McLemore
Kaman Sciences Corporation
Dikewood Division

ABSTRACT

The EMP Test Aircraft (EMPTAC), owned by the Air Force Weapons Laboratory (AFWL), was subjected to high level pulse testing in both the VPDII and Trestle simulators as well as low level CW testing during the summer of 1987. The low level CW testing was performed at the HSI simulator employing both the common and differential modes for the antenna. Wire, bulk and shield currents as well as open circuit voltages were measured for a number of cables inside the aircraft while derivative surface current densities, magnetic, and electric fields were measured on the external surfaces or outside the aircraft. The following five norms were calculated for the measurements in each simulator:

$$N_1 = |f(t)|_{max} \qquad \text{Peak Value}$$

$$N_2 = \left|\frac{df}{dt}\right|_{max} \qquad \text{Peak Derivative}$$

$$N_3 = \left|\int_0^t f(x)\,dx\right|_{max} \qquad \text{Peak Impulse}$$

$$N_4 = \int_0^\infty |f(x)|\,dx \qquad \text{Rectified Impulse}$$

$$N_5 = \left\{\int_0^\infty [f(x)]^2\,dx\right\}^{\frac{1}{2}} \qquad \text{Root Action Integral}$$

Linear regression analyses of pairs of norms will be examined for each of the simulators (in each mode). Special attention will be focused on examples where large deviations exist between a given norm pair and its associated least squares predictor. Further, the degradation detection capability of groups of norms, contrasted with that of a single norm used alone, will be addressed.

REVISING SPECIFICATIONS AND STANDARDS TO INCLUDE EMP-HARDENING CONSIDERATIONS

Jeffrey Casper
SRI International
333 Ravenswood Avenue
Menlo Park, California 94025
(415) 859-5829

Abstract

SRI International has reviewed for the U.S. Army Harry Diamond Laboratories twenty-seven military specifications, standards, and handbooks for their relevance to protecting systems from the effects of the EMP. Revisions were submitted to the Defense Standardization and Specification Program (DSSP) for twelve of the documents. The proposed changes were designed to:

- Correct poor grounding, bonding, and shielding practices
- Clarify ambiguous descriptions of grounding, bonding, and shielding practices.
- Include EMP-hardening programmatic considerations
- Include human-engineering design criteria consistent with EMP hardening requirements.

The presenter will explain the review and revision process, provide examples of recommended revisions, and report on the status of these military documents.

Shielding Specification and Verification Based on the Generalized Shield Concept

Torbjörn Karlsson
Swedish National Defense Research Institute (FOA)
Box 1165, 581 11 Linköping, Sweden.

Today, shielding specifications are mostly written in a very simple way like: "80 dB according to Mil.Std 285". The advantages of such a proceeding seem to be obvious. The engineer knows from experience that there will be sufficient shielding, the manufacturer recognizes the requirements and knows from experience how to produce a shield corresponding to the specification.

There are also disadvantages. The shielding level determined by the experience of the engineer will probably turn out to be conservative in order to guarantee the system to function, which in practice means that a number of unnecessary measures have been taken. On the other hand, the specified shielding may not be sufficient because it is in general impossible to transform the actual coupling attenuation requirements into a Mil.Std 285 specification and vice versa. Nor can appropriate filter attenuation, a most crucial parameter, be derived from this simplified specification. This discrepancy between the need and the resulting unbalanced design represents a significant extra cost and will sometimes exclude an optimal solution where the designer can allow the use of windows and open doors when possible.

A functional shielding requirement should be based on the need for attenuation of coupling which is topologically defined by the generalized shield. The generalized shield *represents* an attenuation of coupling, and defines a maximum allowed coupling (MAC) between relevant circuits on different sides of the shield. If the configuration of circuits within the shield is known in advance, the requirement should best be written in terms of coupling to those circuits. More often there is a need for future flexibility which includes new equipment and reconfiguration of the installation. Then, a useful generic shielding requirement can be formulated as maximum allowed coupling between worst case test circuits such as parallel loops or more sophisticated constructions. The test circuits must be designed and located with regard to exclusion volumes where no installations are allowed.

Verification of the functional requirement is straight forward. The test circuits are easy to produce and the coupling can be measured. If, for some reason, a relative shielding effectiveness (like in Mil.Std 285) is required, the coupling level may be defined relative to some other coupling level (e.g. without the shield) thus creating a generalized shielding effectiveness which may be expressed in dB.

The important feature of the functional shielding requirement to include natural attenuation of coupling, offers the possibility to accept a shield room with apertures. Special doors with contact fingers are expensive, bulky and heavy to operate and should be installed only if necessary. Windows will improve the work environment considerably in a shielded room and may be feasible if the resulting generalized shield is sufficiently good.

IMPROVEMENTS TO MIL-STD 461C CS10 AND CS11 TESTS

G. Oberto, G. Rostagno, Aeritalia GEQ, 10072 Caselle, Italy

ABSTRACT. A radiated NEMP pulse is coupled into electronic circuits through equipment case and cableform. The EMP spectrum is filtered by the cable transfer function and the coupled current shows a spectrum that is enhanced at the poles frequencies of the cableform and input circuitry. The CS10 and CS11 tests reproduce this behaviour by injecting a damped synusoid corresponding to part of the NEMP spectrum from 10 KHz to 100 MHz. The generator output is calibrated at different frequencies on a 100 Ohm loop to reach the specification limit, recording the corresponding generator output voltages. During the test, the same energy is injected into the cableform. The injection is repeated at different frequencies (e.g. 10 KHz, 100 KHz...) and at the U.U.T. typical frequencies (e.g. clocks, L.O., I.F.). The cableform coupled current has the same damped shape of the one measured during the calibration phase.

On the other hand, injecting the damped synusoid at the resonant frequencies (where a maximum or a minimum in the cableform impedance has been measured), the coupled energy shows a resonant behaviour, and the peak of the coupled signal is not reached at the first half cicle but after a few periods. The peak value can be much higher than the first half cicle value, depending on the damping factor "Q" of the cableform impedance at that frequency. When the injection is performed at a minimum of the cableform impedance, the coupled current, measured by a current probe, presents a maximum.When the injection is performed in a maximum of the cableform impedance, the coupled voltage presents a peak. This voltage can be measured at the coupling device (e.g. using a single turn loop if the coupling device is a transformer). In both cases the maximum coupling is reached by performing a fine adjustment of the generator frequency and of the coupling device along the cableform. The test performed at the cableform resonant frequencies is the one that better reproduce the effects of the coupling between the radiated field and the cableform under test and represent the more severe test for susceptibility detection.

OVERVIEW OF DOD-HANDBOOK ON "HAMS PLANNING GUIDELINES"

Major Raymond T. Odierno
HQ DNA/PRAS, Washington, D.C. 20305

William A. Brummer
Science & Engineering Associates, Inc.
Box 3722, Albuquerque, N.M. 87190

The need for preserving and verifying nuclear hardness throughout the operational life of a weapon system is emphasized in DoDI 4245.4 and in each of the Service's implementing regulations. In an effort to help satisfy this need, HQ DNA is developing guidelines to aid in planning for hardness assurance, maintenance, and surveillance (HAMS) during the production and operations phases of a system's life cycle. These guidelines are scheduled to be available as a draft military handbook in December, 1988.

The intended users of this handbook are weapon system program managers (and their staff) and requirements writers. It provides very top level HAMS planning guidelines which are applicable to all DoD agencies, to all types of weapon systems, and to all nuclear effects. It identifies principles and procedures for defining HAMS concepts from which detailed activities can then be determined. The procedures conform to the phased structure of the system acquisition life cycle which is already familiar to program managers. The guidelines are equally applicable for existing system modifications and for new systems.

This handbook provides a common, DoD-wide basis for managing for an effective lifetime HAMS program. Principles are presented which form the basis for a HAMS planning methodology which can be performed efficiently, effectively, and completely. This methodology is presented as 21 specific tasks to be accomplished by requirements writers and system program managers throughout the acquisition life cycle. For each task, the handbook describes the why, what, where, and when, as well as specific examples of how the task has been accomplished in actual practice. Appendices to the handbook are included to provide detailed "boilerplates" detailing how to include HAMS considerations in program management documentation such as Mission Need Statement, Nuclear Hardness Program Plan, and Request for Proposal. Other appendices list program management documentation, Government regulations, and data item descriptions which relate to HAMS.

These "HAMS Planning Guidelines" are being developed by a Government-industry team. While most of the handbook is being written under contract, Government personnel representing a broad spectrum of DoD agencies are involved in the development. They are reviewing the contractor's efforts, identifying example systems to be included, and "trying-out" the guidelines to confirm that they are, in fact, practical and realistic.

SESSION P1

PLENARY SESSION

Chairman: W. Graf, SRI International, Menlo Park, CA

Wednesday, 18 May (morning) Building I, Auditorium

1 8:30 **EMP Activities in Israel**, J. Shiloh, Haifa, Israel

2 9:00 **Soft Kill? Da!**, R. Wagner, Kaman Sciences Corporation, Alexandria, VA

3 9:30 **EMP/RF Hardening**, G. August, SRI International, Menlo Park, CA

10:00 Coffee Break

4 10:30 **Specifications and Standards**, E. F. Vance, SRI International, Menlo Park, CA

5 11:00 **EMP Vulnerability is Real**, D. Hansen, BBC Brown Boveri Ltd., Baden-Daettwil, Switzerland

6 11:30 **The Phenomenology of HPM Interaction with Systems**, H. S. Cabayan, Lawrence Livermore National Laboratory; K. S. H. Lee, Kaman Science Corporation (Dikewood Division), Santa Monica, CA

E M P ACTIVITIES IN ISRAEL

J. Shiloh

RAFAEL, P.O.Box 2250, Haifa Israel

EMP activities in Israel have been growing since 1980, when the Israeli EMP Center was established in RAFAEL by the MOD (Ministry of Defence). RAFAEL is the Armament Development Authority which is part of the MOD. EMP policy is determined by the MOD for systems that are developed for the IDF (Israeli Defence Forces).

Activities in RAFAEL include enviroment and interaction calculations, hardening technology, vulnerability and succeptibility studies, simulator development, and simulation tests. The center provides all necessary services, regarding these subjects, to the Israeli Defence Industries during the development phase of systems for the IDF. HEMP fields are studied with a code based on fourh order Runge Kutta numerical integration. Parametric studies for various geometric factors and extreme cases of gamma ray functions are performed to determine the threat. Such calculations are compared to other results in the literature.

All simulators are developed in RAFAEL for its own use. The same simulators are also being produced and marketed by ELGAL - a subsidiary of RAFAEL. The facility includes three bounded wave simulators, the largest one being 20 m in maximum hight. In addition a hybrid type HPD is now being erected. A variety of injection simulators and test methods were developed covering most present day standards, in addition to an inductive coupling system capable of simulating large current on a long cable.

The presentation will include discussion on the general threat preception in Israel and the various activities with emphasis on enviroment calculations and test methods for EMP hardening evaluation.

STANDARDS AND SPECIFICATIONS

by

Edward F. Vance, SRI International

ABSTRACT

The evolution of standards is followed from the earliest weights and measures used in commerce to modern measures of interchangeability and product quality. Standard threads, metal and wire gauges, and pipe sizes accommodate worldwide trade in mass produced goods that are compatible and interchangeable. Standards of performance for electronic equipment permit units to share a common data bus, a common power supply, and a common system volume. The EMP protection is a system performance property that can be standardized. The buyer and seller can then agree at the outset on how the system is expected to perform in an EMP environment. However, failure to meet the EMP protection requirement is not evident in day-to-day use of the system. Partly because of this, operating personnel may not recognize symptoms of protection failure or of EMP-induced irregularities. Hence, special EMP protection techniques and validation considerations are necessary.

EM Vulnerability is Real

D. Hansen
BBC Brown Boveri Ltd.
5405 Baden-Daettwil/Switzerland

There is increasing evidence that severe electromagnetic environments can result in the breakdown of electronic systems, sometimes accompanied by catastrophic results. Several peacetime examples of "EMI accidents" from the open literature will be reviewed. These accidents involve both civil and military systems and have occurred at various places around the world, including Europe and the United States. The problem is only compounded if EMP sources are also present during wartime. A short film, dealing with the damaging effects of hostile electromagnetic environments, will also be screened as part of this presentation.

THE PHENOMENOLOGY OF HPM INTERACTION WITH SYSTEMS

H. S. Cabayan

Lawrence Livermore National Laboratory

K. S. H. Lee

Kaman Science Corp. (Dikewood Division)

In this paper, the authors will derive upper bounds to HPM environments from first principle considerations that depend on aperture and air breakdown physics. In the interaction phenomenology, the authors will derive scaling laws in coupling and susceptibility that depend on fluence, frequency, polarization, angle of incidence, and pulse width. Finally, the authors will discuss simulation fidelity issues.

SESSION 6A
ASSESSMENT: ASSESSMENT OF REAL SYSTEMS

Chairman: W. Petty, Harry Diamond Labs, Woodbridge, VA
Wednesday, 18 May (afternoon) Building I, Auditorium

1 1:30 **The Effects of Electromagnetic Pulse (EMP) on Army Field Medical Equipment**, Maj. R. H. Vandre, Frederick, MD; J. Klebers, IRT Corp., Vienna, VA; F. Tesche and J. P. Blanchard, LuTech, Lafayette, CA

2 1:50 **Some Elements of the NEMP Analysis of a Swiss Electromechanical Locomotive Type Re 4/4" - Experiment and Theory**, D. Hansen, H. Schaer, D. Koenigstein, and N. Ari, Brown Boveri, Switzerland

3 2:10 **HEMP Coupling Phenomenology to a Ground Radar System**, G. W. Mock, Hughes Aircraft Company, Fullerton, CA

2:30 Coffee Break

4 3:00 **EMP Testing of Large Fixed Installations**, K. G. Lövstrand, Defence Materiel Administration, Sweden

5 3:20 **Pin Level Current Responses for a Large Space Structure**, M. Stieglitz and J. Tigner, SAIC, McLean, VA

6 3:40 **Experimental NEMP Analysis of a Private Telephone Branch Exchange Including Field Calculation for the Working Volume of a Bounded Wave Simulator**, D. Hansen, D. Koenigstein, and H. Garbe, BBC Brown Boveri Ltd., Switzerland

7 4:00 **Simulated EMP Aircraft Responses as a Function of the Angle of Incidence**, P. Mani, NC Laboratory Spiez, Switzerland; F. M. Tesche, LuTech, Inc., Dallas, TX

8 4:20 **Hardness Degradation Experiments Performed on EMPTAC**, W. Bereuter and B. Moser, MRC; S. Kokorowski, Kaman Sciences Corp., Dikewood Div.; K. Gallegos, Air Force Weapons Laboratory

6:30 Awards Banquet at the Holiday Inn, Palo Alto

The Effects of Electromagnetic Pulse (EMP) on Army Field Medical Equipment

Robert H. Vandre, Maj, DC, Commander, USA IDR, C/O USAMBRDL, Ft. Detrick, Frederick, MD 21701-5010; **John Klebers**, IRT Corporaton, 1953 Gallows Rd. Suite 200, Vienna, VA 22180; **Fred Tesche, Janie P. Blanchard,** Lu Tech, Inc. 3742 Mt. Diablo Blvd., Lafayette, CA 49549

ABSTRACT

This paper summarizes the results of experimental and analytical studies on the nuclear electromagnetic pulse (EMP) vulnerability of medical equipment used in Army field hospitals. Medical equipment, just like other systems with sensitive electronic components, is susceptible to EMP. These studies provide the first major data set compiled to date for this equipment class.

Most medical equipment, with one or two exceptions, falls into the category of non-developmental items (NDI) for the Army. Hence, the electronic design has no EMP protection incorporated. Army field hospitals, however, have equipment, such as x-ray and emergency life support systems, which are critical to operations in the nuclear battlefield. It is important that the EMP vulnerabilities of these equipments are known, and that protective measures are developed to insure their survivability to EMP exposure.

Results of EMP testing of medical equipment at the Harry Diamond Laboratory's AESOP simulator and interface circuit EMP susceptibility analyses conducted on a significant number of medical equipments are presented. Seven medical equipments were tested in the AESOP EMP simulator at the Harry Diamond Laboratory's Woodbridge Research Facility. Of these, two of the equipments with longer sensor/control cables were damaged by the simulated EMP pulse. Seventeen medical equipments were analyzed for EMP susceptibility. Damage for the assumed 10mJ threat was predicted for 65% of this equipment group.

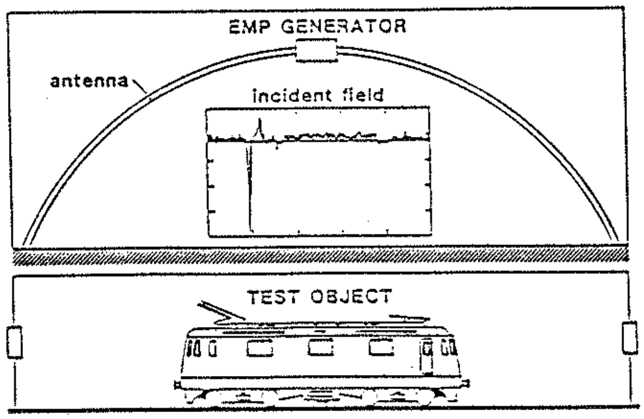
Since it is not feasible at this time to harden individual medical equipments in the present inventory, basic EMP mitigation methods which would enhance the EMP survivability of medical equipment were explored, and are summarized. One such EMP mitigation method presented is the deployment of long cables in the North-South directions. Results of EMP cable coupling calculations using new EMP environment predictions as source terms are presented.[1] These calculations show that cables lying in the North-South direction will, on the average, have substantially lower EMP induced than cables lying in the East-West direction.

---

1 Longmire, C.L. et al, "A Nominal Set of High Altitude EMP Environments," Oak Ridge National Laboratory, ORNL/Sub/86-18417/1, MRC. April 1986.

Some Elements of the NEMP Analysis of a Swiss Electromechanical Locomotive Type Re 4/4" - Experiment and Theory -

D. Hansen, H. Schaer, D. Koenigstein, N. Ari
BBC Brown Boveri Ltd.
NEMP / EMC Section
5405 Baden-Daettwil / Switzerland



For the first time a complete electromechanical locomotive of the Swiss Federal Railway Company has been subjected to simulated EXO NEMP fields by means of an HPD simulator (MEMPS). During the course of the project theoretical and experimental investigations have been performed including an analysis of a subsystem (UHF radio link) which is part of the locomotive. These typical components are part of the Swiss Railway Network which is to be hardened against EXO NEMP at the points of energy entrances into the system [1]. The analysis and theoretical data of the evaluated system and subsystem parts include

- short external transmission line
- transmission line behind aperatures within the locomotive
- UHF antenna system

The experiments indicate that other types of locomotives, such as diesel electrical engines, could seriously be affected by EXO NEMP field coupling.

The UHF telecommunication system was additionally investigated in detail (subsystem test) in the novel BBC GTEM cell [2].

Work is under way concerning a final system integration test including "power on" tests and EMP current injection.

References

[1] K.S.H. Lee, ed., "EMP Interaction: Principles, Techniques and Reference Data (A Compleat Concatenation of Technology from the EMP Interaction Notes)", EMP Interaction 2-1, Dec. 1980, Report AFWL-TR-80-402

[2] D. Koenigstein, D. Hansen, "A New Family of 50 Ohm TEM-Cells with Enlarged Bandwidth and Optimized Working Volume", 7th Symposium and Technical Exhibition on Electromagnetic Compatibility, Zurich, March 1987

HEMP COUPLING PHENOMENOLOGY TO A GENERIC GROUND RADAR (GGR) SYSTEM

Gil W. Mock

HUGHES AIRCRAFT CO.
Ground Systems Group
P.O. Box 3310
Fullerton, CA 92636

ABSTRACT

A radar system under study consists of four shelters and an antenna group. Three shelters are used to house the transmitter/receiver electronics, support equipment and computer complex. The other shelter is the antenna truss to house the beam steering electronics and environmental control circuits. The antenna group consists of the Primary Search Radar (PSR) Array, Secondary Search Radar (SSR), Clear Channel Sensing (CCS) and Sidelobe Blanking (SLB) antennas. In the operational radar site, interface cables and waveguide runs are the interconnecting links between shelter complex and antenna group. The radar system is, generally, deployed in a location on top of a mountain. The system will be powered by a generator located approximately 100 meters away from the shelter complex. Telephone, teletype and other communication links will be routed to the modem complex from a distance of 200 meters to 1.6 kilometers. To develop the coupling phenomenology for such a complex radar system, it is necessary to study the topology of the system for each penetration. These penetrations are then separated into deliberate and non-deliberate antennas. The coupling phenomenology depends on the geometry and location of each penetration. For a simplified and systematic approach to analysis of the overall system, the radar system complex is divided into different zones. The coupling phenomenology of the penetrations at each zone will involve both the external and internal coupling analyses. Requirements are then derived for the interface bulk current, core current and necessary conductive paths at the interface of each zone.

EMP TESTING OF LARGE FIXED INSTALLATIONS

Dr. KARL G Lövstrand,
Defence Materiel Administration,
Air Materiel Testing Directorate,
Linköping, Sweden

Abstract.

A method has been developed for EMP hardness verification of large fixed installations. The verification principle is a composite of a careful design review of shielding structures and electrical installations and local testing of each point of entry (POE) area in the generally well shielding external structures of the installations.

A multiple pulse current injection system which can also drive a Bounded wave antenna is used for the testing. The test system is fully portable and can be carried by a small van.

By transformer coupling it is possible to inject full EMP threat pulse currents into underground cables of maximum 100 mm diameter. The risetime and tail of the pulse can be selected according to a predicted threat. It is thus possible to inject by transformer coupling current pulses with a risetime of less than 100 ns and a duration of several µs. Four pulses can be injected simultaneously or with a controlled time delay between two groups of cables. The 100 kV generator driving the current transformers can also be used for the 4m tall and 30m long portable 100 Ω Bounded wave antenna, with an E-field rise time of less than 10 ns, in order to illuminate local apertures such as entrances into shielded buildings. External and internal measurements are made with transient digitisers and fiber optic link signal transmission.

Testing of a large underground installation consisting of several underground buildings over an area of about 1 km diameter, is presented as an application of the verification method.

The EMP-hardness is demonstrated by the measured attenuation of electromagnetic energy from external fields and currents into internal electrical systems for each POE-area.

The verification method requires a systematic design of the installations with a good overall shield with a limited number of POE's.

PIN LEVEL CURRENT RESPONSES FOR A LARGE SPACE STRUCTURE*

Marc Stieglitz and John Tigner
Science Applications International Corporation
1710 Goodridge Drive
McLean, Virginia 22102

ABSTRACT

In this paper a methodology is developed by which time domain waveform data from a current injection test (CIT) on a present day satellite is employed to estimate the pin level current responses due to SGEMP for a large space structure.

Future space systems may include space platforms which differ structurally from present day satellites. In particular, the Strategic Defense Initiative Program has proposed deploying large space structures, such as particle beam platforms, battle managers, and laser platforms in space. While present day satellites typically appear as that shown in Figure 1, future space platforms may be quite long in the transverse dimension (Figure 2). While extensive Current Injection Testing (CIT) has been performed on present day satellites to assess satellite survivability in hostile nuclear environments, no such testing has been performed on large platforms, since none have yet been built. This paper utilizes CIT data for present day satellites. These data are employed in concert with an analysis of expected body currents to assess survivability issues associated with large platforms stressed by hostile nuclear environments.

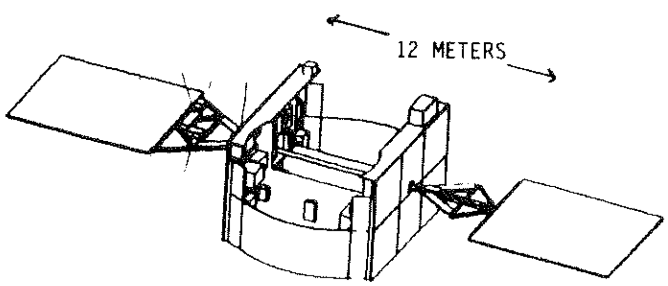


Figure 1. A Typical Present Day Satellite

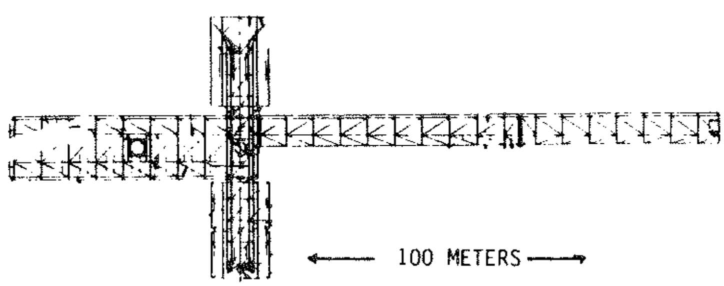


Figure 2. Model of a Hypothetical Large Space Structure

*This work sponsored by the Air Force Weapons Laboratory under Contract F9601-82-C-0023 and Computer Sciences Corporation Subcontract S-289.

Experimental NEMP Analysis of a Private Telephone Branch Exchange Including Field Calculation for the Working Volume of a Bounded Wave Simulator

D. Hansen, D. Koenigstein, H. Garbe
BBC Brown Boveri Ltd.
NEMP / EMC Section
5405 Baden-Daettwil / Switzerland

Investigations to assess the potential disabling effect of HEMP-bursts on fully operational switches have recently been reported [1-2]. From the standpoint of national security it is important to know the survivability of private branch exchanges (shielded) and their associated subscriber equipment (unshielded).

For the experimental evaluation presented here, only a bounded wave type simulator was available [3]. Because of the known imperfections of these simulators, a theoretical prediction of the field homogenity was performed. This was achieved using a MOM-computer code [4].

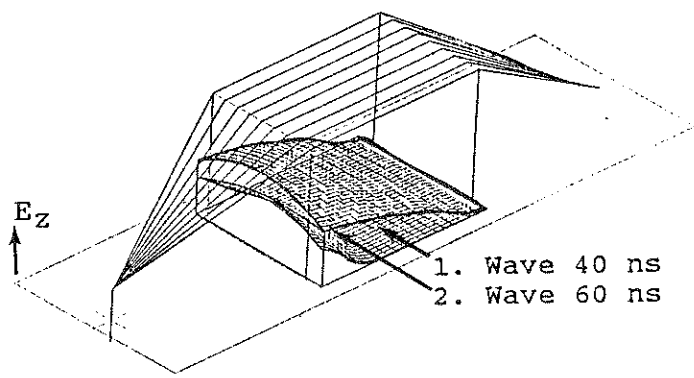


Figure 1 shows the E-field distribution at different time intervalls in the working volume. This is in excellent agreement with the experimental results from the test volume.

The field impact on an active exchange system (CMOS-Technology) and a telephone set respectively have been measured. Examples of induced transient currents will be shown.

EMI hardening improved the NEMP survivability of the exchange system considerably. The unprotected telephone set including micro-processors, was burnt out at roughly 30 kV/m. With adequate terminal protection the telephone set survived 50 kV/m.

References

[1] N.A. Beauchamp e.a.: "Nuclear Weapons Effects Studies for the 5th ESS™ Switch", Vol. III:" EMP Studies", Part 1: "Testing and Analysis", DCA 100-85-C-0094
[2] N.A. Beauchamp e.a.: "Nuclear Weapons Effects Studies for the 5th ESS™ Switch", Vol. II: "EM-Shielding Characteristics of Structures", DCA 100-85-C-0094
[3] K. Feser e.a.: "MIGUS: A Flexible Fully Automatic EMP Simulator", 7th EMC Symposium, Zurich, 1987
[4] H.D. Bruens: "Pulserregte elektromagnetische Vorgänge in dreidimensionalen Stabstrukturen", Doctor Thesis, University of the Federal Armed Forces, Hamburg, 1986

SIMULATED EMP AIRCRAFT RESPONSES AS A FUNCTION OF THE ANGLE OF INCIDENCE

P. Mani
NC Laboratory Spiez
CH-3700 Spiez
Switzerland

and

F.M. Tesche
LuTech, Inc.
PO Box 796012
Dallas, TX 75379
USA

ABSTRACT

A recent Swiss EMP test of an aircraft in an in-flight configuration provided a unique opportunity to measure the behavior of EMP-induced fuselage currents and internal bulk cable currents as a function of the angle of incidence of the EMP. Instead of using a dielectric test platform to elevate the aircraft, a wooden hoist was constructed and the aircraft was lifted approximately 8 meters into the air. In this way, a realistic in-flight test was performed with the wheels up and the engine running.

The aircraft was rotated on the hoist to provide EMP illumination over a range of 180 degrees, from nose-on incidence to incidence from the tail. Such data show that the largest longitudinal fuselage current occurs when the fuselage is parallel to the simulator. However, the largest internal cable current occurs with the aircraft at a skew angle with respect to the simulator.

This paper discusses the measured data and illustrates several data processing schemes used to interpret the data. An averaging of the spectral magnitudes can be useful in extracting the natural (SEM) resonances of the aircraft and the internal cables.

HARDNESS DEGRADATION EXPERIMENTS PERFORMED ON EMPTAC

W. Bereuter
B. Moser

Mission Research Corporation

S. Kokorowski

Kaman Sciences Corporation
Dikewood Division

K. Gallegos

Air Force Weapons Laboratory

ABSTRACT

The EMP Test Aircraft (EMPTAC) owned by the Air Force Weapons Laboratory(AFWL) has been modified to incorporate typical hardening features such as shielded volumes and bays, filters and shielded cables, and other penetration protection treatments found on military aircraft. The EMPTAC was then EMP simulation tested at AFWL during May to September 1987 in low level CW simulators (HSI common and differential modes), high level pulse simulators (TRESTLE, VPD-II), and with local exciters (striplines, direct drive). Hardness degradation experiments were performed to evaluate different test techniques for detecting, locating, and determining the significance of hardness faults. To this end, hardness faults observed on several hardened airborne systems were reviewed and a representative set of degradations was selected for implementation on the EMPTAC. These fall basically into the following categories:

ELECTRICAL LINE DEGRADATIONS: Cable shields and connectors, filters
APERTURES: Window shields, hatch and cargo door seals
MECHANICAL LINE PENETRATIONS: Control cable penetration hardening treatments

Response measurements were made with and without the simulated degradations in place to observe coupling changes. A number of different data analysis algorithms were then employed to evaluate their utility for detecting and locating hardness faults. The results of these test and analysis efforts will be presented. Different fault detection and location methods will be discussed and compared.

SESSION 6B-1

INTERACTION: LINE PENETRATIONS

Chairman: P. Johns, University of Nottingham, United Kingdom
Wednesday, 18 May (afternoon) Building A, Conference Room B

1 1:30 **Penetration Transfer Impedance and Admittance -- The Intrinsic Electromagnetic Parameters for Specifying Filters, Bonds, Isolators, and Other Devices for Treating Conductive Penetrations,** L. O. Hoeft and J. S. Hofstra, The BDM Corporation, Albuquerque, NM

2 1:50 **Electromagnetic Characterization of Line Penetrations,** K. F. Casey, JAYCOR, Fremont, CA

3 2:10 **High Frequency Coupling Through an Aperture Penetrated by a Wire,** D. B. Wright, University of Arizona, Tucson, AZ; R. J. King, Lawrence Livermore National Laboratory, Livermore, CA

2:30 Coffee Break

4 3:00 **Extraction of Poles from Correlated EMP Responses of Difference Systems,** P. Catalano, Aeritalia, Caselle, Italy

5 3:20 **Hybrid EMP Surge Suppression,** M. A. Caruso and J. Breitmeier, Shielding Systems Corporation, Ray Proof Division, Norwalk, CT

SESSION 6B-2

INTERACTION: SHIELDING

Chairman: R. King, Lawrence Livermore National Laboratory, CA
Wednesday, 18 May (afternoon) Building A, Conference Room B

1 3:40 **Electromagnetic Shielding Behavior of Wire-Mesh Screens,** K. F. Casey, JAYCOR, Fremont, CA

2 4:00 **An Investigation into the Use of Metallized Fabric Enclosures for the Protection of Electronic Medical Equipment from EMP,** S. H. Sands and J. P. Blanchard, LuTech, Inc., Lafayette, CA; Maj. R. Vandre, U.S. Army Institute of Dental Research, Ft. Detrick, Frederick, MD

3 4:20 **Experimental Definition of Susceptibility Criterion for Numerical Transmission Systems,** G. Ferrero and L. Giorcelli, Aeritalia, Italy

6:30 Awards Banquet at the Holiday Inn, Palo Alto

PENETRATION TRANSFER IMPEDANCE AND ADMITTANCE-- THE INTRINSIC ELECTROMAGNETIC PARAMETERS FOR SPECIFYING FILTERS, BONDS, ISOLATORS, AND OTHER DEVICES FOR TREATING CONDUCTIVE PENETRATIONS

Lothar O. Hoeft and Joseph S. Hofstra
The BDM Corporation
1801 Randolph Rd., S.E.
Albuquerque, NM 87106
(505) 848-5399

Penetration transfer impedance is the ratio of the open circuit voltage on the inside of a conductive penetration treatment, divided by the current on the outside. It is an intrinsic electromagnetic parameter that characterizes shunt devices, such as filters, bypass capacitors, and bond straps that are used to reduce the currents that can get into a shielded volume by means of conductive penetrations. Penetration transfer admittance is the ratio of the short circuit current carried by the internal circuit, divided by the voltage across the external terminals. It is the corresponding parameter for series type hardening elements. Laboratory measurements, carried out as part of this effort shows that these parameters are relatively easy to measure and are much more meaningful and easier to interpret than insertion loss because they do not depend on the impedance of the measurement setup. Their use should facilitate the electromagnetic analysis of hardened systems and provide a common basis for the specification and measurement of conductive penetrations, one of the most critical elements of shielding design.

ELECTROMAGNETIC CHARACTERIZATION OF LINE PENETRATIONS

Kendall F. Casey

JAYCOR
39650 Liberty St., Suite 320
Fremont, CA 94538

A canonical boundary-value problem in electromagnetic theory is formulated and solved in order to characterize a line penetration into an otherwise shielded region. It is found that the line penetration can be described in terms of equivalent-circuit and transmission-line models. The transmission-line model is based on the "quasi-TEM" behavior of the penetrated current. Representative analytical and numerical results are presented to illustrate the behavior of the transmitted current as a function of frequency, for unprotected penetrations and for penetrations which are protected by conductive and inductive shunt admittances. It is shown that resonance effects associated with the use of inductive shunts can cause the penetrated current to exceed its "unprotected" value over a broad frequency range.

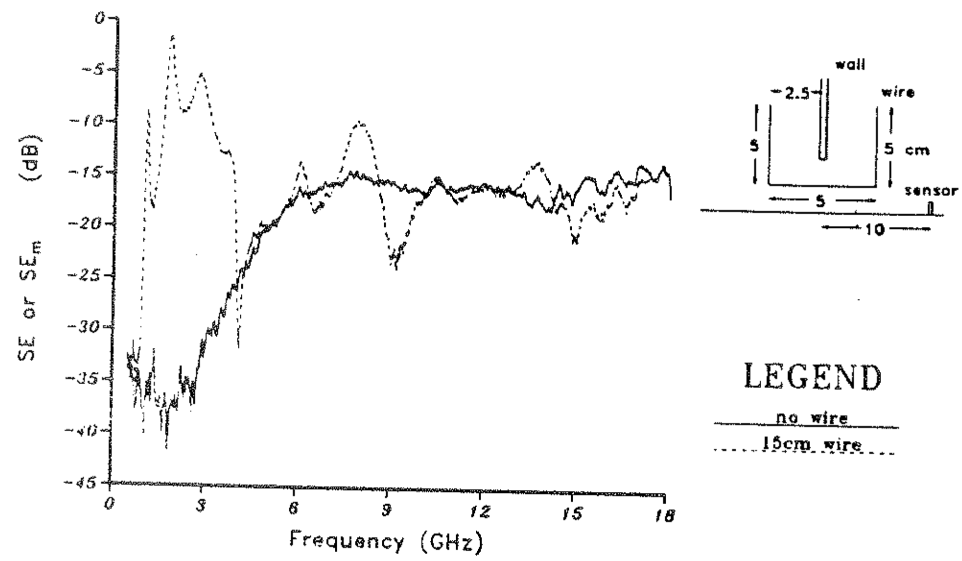
HIGH FREQUENCY COUPLING THROUGH AN APERTURE PENETRATED BY A WIRE*

D. B. Wright
ECE Dept., University of Arizona
Tucson, AZ 85721

R. J. King
Lawrence Livermore National Laboratory
L-156
Livermore, CA 94550

ABSTRACT

The effect on aperture coupling produced by the insertion of a penetrating conductor was investigated experimentally. A thin, single wire was used as the penetrating conductor. It was observed that when the first TEM resonant frequency of the wire, f_w, is less than the cutoff frequency of the aperture, f_a, the wire can provide complete coupling to the incident field, effectively destroying any shielding provided by an exterior metal hull. Above f_a, although the aperture dominates, the penetrating conductor introduces complicated, resonant behavior. Data collected by an interior sensor are presented in terms of shielding effectiveness (SE) which is defined as the ratio of the sensor current with shielding in place to the current with shielding removed.



SE for 2.0 cm x 1.0 cm aperture alone versus SE$_m$ for 15 cm wire through same aperture (f_w = 1.0 GHz, f_a = 3.75 GHz)

Ref: D. B. Wright and R. J. King, "Phenomenology of Electromagnetic Coupling: Conductors Penetrating an Aperture," Lawrence Livermore National Laboratory, UCID-21087, June, 1987.

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

Extraction of poles from correlated EMP responses of different systems

P. Catalano, Aeritalia GEQ, 10072 Caselle (TO), Italy

The basic objective of this paper is to study the main differences between some well known methods for the computation of the singularities of EMP coupled systems.

In particular three methods are analyzed (Prony, Pencil of Function, Pisarenko or Eigenvalues method), concerning the stability of the solution in absence of noise.

All three methods solve a linear system to find the coefficients of an algebric equation, whose zeroes are the poles of the system under test.

It has been noticed that the first two methods do not perform as well as the third one in resolving the singularities of correlated EMP responses of two different systems.

In these cases one has to deal with very ill conditioned matrixes; therefore the number of singularities is underestimate and the obtained poles are completely different from the true ones.

Some examples are proposed to illustrate this problem.

ELECTROMAGNETIC SHIELDING BEHAVIOR

OF WIRE-MESH SCREENS

Kendall F. Casey

JAYCOR

39650 Liberty St., Suite 320

Fremont, CA 94538

The electromagnetic shielding behavior of bonded-junction wire-mesh screens is discussed in the frequency range where the individual meshes are electrically small. The screen, whose meshes are assumed to be square, is described by an equivalent sheet impedance operator. The plane-wave shielding effectiveness of a planar mesh screen is derived and the low-frequency electric and magnetic shielding afforded by mesh enclosures is considered. Because of the reactive character of the mesh surface, the plane-wave shielding effectiveness decreases with increasing frequency. The enclosure magnetic-field shielding effectiveness increases with increasing frequency, but saturates at a maximum value which depends on the geometry of the enclosure, the mesh size, and the mesh wire radius. The enclosure electrostatic-field shielding effectiveness depends only on the enclosure and mesh geometries.

An Investigation into the Use of Metallized Fabric Enclosures for the Protection of Electronic Medical Equipment from EMP

S.H. Sands
J.P. Blanchard
LuTech, Inc.
3742 Mt. Diablo Blvd.
Lafayette, CA 94549

Maj. R. Vandre
US Army Institute of Dental Research
c/o USABRDL
Ft. Detrick
Frederick, MD 21701-5010

Abstract

Nuclear Electromagnetic Pulse (EMP) has been shown to be a threat to modern electronic equipment. This paper focuses on one approach investigated for hardening of medical equipment used by the military in field hospitals.

One approach to EMP hardening of existing medical equipment involves retrofitting each piece of equipment with various hardening measures. The cost to accomplish this, however, becomes prohibitive when the number of pieces of equipment is tallied. An alternate approach, investigated here, is to reduce the EMP environment inside the field hospitals to tolerable levels.

This method involved the use of metallized fabrics to form a tent or enclosure. The investigations were concerned with comparing the shielding capabilites, using both CW and high level pulse illumination, of two types of metallized fabrics, when made into an enclosure.

As part of this investigation, an analytical model was constructed to predict the shielding effectiveness (defined as H_i/H_o) of the fabric enclosure. Comparison of predicted and test results is seen to be excellent.

EXPERIMENTAL DEFINITION OF SUSCEPTIBILITY CRITERION FOR NUMERICAL TRANSMISSION SYSTEMS

G. Ferrero - L. Giorcelli

AERITALIA G.eq. - EMC Group
Caselle T.se - ITALY

Summary

This paper describes the theoretical approach and experimental tests performed on a digital transmission channel subject to EMI steady-state, aimed to determine the available EMC safety margin. The results of this work give indications about the effects due to EMI on numerical communication lines, as MIL-STD-1553 data bus, installed on aircraft system in terms of margin loss as consequence of signal to noise ratio reduction.

Taking into account the great complexity and modification of the data bus electrical configuration at system level, the mathematical modelling of the overall aircraft is not feasible: cost and time increase and the accuracy of the results decreases with the complexity of the harness being modelled. A solution seems to be experimental measures performed on a 1553 data bus (length = 2.5 m), implemented with four coupler boxes in our case, excited by a pattern generator and loaded with an error detector operating a bit to bit control. The performance of the digital communication system is measured in terms of the bit error probability P_E defined as P_E = P (bit tx $\neq$ bit rx). The gaussian white noise has the effect of increasing the BER to the appropriate value in order to carry out the test in reasonable time. The error probability curve for this reduced PAM binary system operating in nominal conditions has been measured and plotted.

Further measurements then have confirmed that the analysis can be limited to the in band frequency range. In order to define a sensitivity map (parametrical curves) representing the system, the disturbances must be injected through the coupler box, and the amplitude should be increased step by step. The sensitivity map is marked out, injecting the RF signals equivalent to disturbance starting from the nominal characteristic system curve, and plotting the curve corresponding to the RF signals.The curves parameter is the RF signal amplitude equivalent to the steady-state disturbances. On the basis of this map it's possible to evaluate the EMI effects performing a graphical operation and measuring the safety margin loss in dB on the signal to noise axis. If the P_E variation is not measurable in presence of considerable EMI the safety margin loss is lower than the measure system accuracy. The applicability of this method may be extended to characterize the numerical communication channels of the aircarft system. The parametrical curves must be plotted for this real situation, in which up to 32 coupler boxes with a relative longer harness are employed.

SESSIONS 6C and URSI E-3

HARDENING TECHNOLOGY: MILITARY AND CIVILIAN SPECIFICATIONS AND STANDARDS

Chairman: G. Schlegel, R&D Associates, Marina del Rey, CA
Wednesday, 18 May (afternoon) Building I, Room S109

1 1:30 **EMP Specifications and Standards for Aircraft,** W. D. Prather, AFWL, Albuquerque, NM

2 1:50 **Nuclear EMP Standardization Committee,** K. -G. Lövstrand and M. Wik, Defence Materiel Administration, Sweden

3 2:10 **Panel Discussion: NEM Civilian Specifications**
Chairman: G. Schlegel, R & D Associates
Panelists:
C. Baum, AFWL
P. Castillo, R & D Associates
W. Graf, SRI International
J. Lubell, Mission Research Corporation
D. McLemore, Kaman Sciences Corporation
W. Prather, AFWL
E. Vance, SRI International

3:10 Coffee Break

6:30 Awards Banquet at the Holiday Inn, Palo Alto

EMP Specifications and Standards for Aircraft

William D. Prather
Air Force Weapons Laboratory
Albuquerque NM

Abstract

In the last two years, since NEM 1986, there have been significant advances in our ability to write EMP specifications for aircraft. Much of this has resulted from the development of techniques for measuring shielding transfer functions on board aircraft. Both localized and system-level techniques for the CW measurement of transfer functions have been developed and demonstrated. As a result, we can now write specifications for aircraft hull hardening, compartment hardening, cable shields and electronic boxes, and each specification has an accompanying measurement technique. The shielding measurement techniques have application in design, quality control, acceptance and hardness maintenance. It is anticipated that within a year, we will have a draft system-level EMP standard available for review.

NUCLEAR EMP STANDARDIZATION COMMITTEE

Karl-Gunnar Lövstrand Manuel Wik
Defence Materiel Administration
S 115 88 Stockholm
Sweden

The Swedish National Committee (SEK) of the International Electrotechnical Commission (IEC) has formed a technical committee TK 77 Y in the field of Protection against Nuclear Electromagnetic Pulse (NEMP). A proposal has recently been forwarded to the IEC Committee of Action. The Swedish National Committee and the proposal will be presented.

DEVELOPMENT OF STANDARDS FOR HEMP PROTECTION OF GROUND-BASED C^3 FACILITIES

Don Arns
SRI International
333 Ravenswood Avenue
Menlo Park, California 94025

Abstract

Under contract to the Defense Nuclear Agency, SRI International is developing military standards and a military handbook for HEMP protection of ground-based C^3 facilities. This paper addresses the need for this series of documents, their structure, and a description of their progress to date.

The merits of standardization for HEMP protection are discussed. Standardization, in the form of understandable written guidance, will

(1) Reduce design risk, time, and costs,

(2) Increase overall (system-wide) performance and life-cycle integrity, and

(3) Give facility designers, fabricators, testers, and users the benefits of the expertise and experience of HEMP protection authorities in an efficient manner.

The standards and handbook being written dictate the use of low-risk hardening for the facilities. The concepts of low-risk hardening are presented, including a brief discussion of topological zoning and allocation of protection among elements of electromagnetic barriers.

The five-volume draft standard and the accompanying handbook are described, with an illustration of how a typical facility would be designed, constructed, made operational, and tested using the documents. Our cooperative efforts with the military departments and other DoD agencies are described, with estimated schedules for delivery of the documents.

SESSION 7A

ASSESSMENT: EMP ASSESSMENT IN POWER PLANTS

Chairman: K. Lövstrand, Defence Materiel Administration, Stockholm, Sweden

Thursday, 19 May (morning) Building I, Auditorium

1 8:30 **CW Illumination of an Underground Facility with Extrapolation to EMP,** Ö. Borgefalk and S. Garmland, EMTECH elmiljöteknik ab, Linköping, Sweden

2 8:50 **Design and Modelling of a 500 kVA EMP Shielded Transformer,** D. Fromme, J. Youngman, and M. Bell, JAYCOR, Colorado Springs, CO

3 9:10 **EMP Test Results for Electrical Distribution and Power Transformers,** C. H. Eichler, Westinghouse Electric, Pittsburgh, PA

4 9:30 **Preliminary Results of High Voltage EMP Power Filter Failure Investigation,** A. Chodorow and D. Schafer, MRC, Albuquerque, NM; Capt. H. Pohle, AFWL, Kirtland AFB, NM

9:50 Coffee Break

5 10:20 **Measurement of Switching Transients in Substations,** C. M. Wiggins, F. S. Nickel, and A. J. Haney, The BDM Corporation, Albuquerque, NM

6 10:40 **Near Field Coupling of Switching Transients to Secondary Circuits in Substations,** D. E. Thomas, C. M. Wiggins, III, and F. S. Nickel, The BDM Corporation, Albuquerque, NM

1:30 Buses leave Holiday Inn for tours

9:00 AM Friday Buses leave Holiday Inn for tours

CW ILLUMINATION OF AN UNDERGROUND FACILITY WITH EXTRAPOLATION TO EMP

Örjan Borgefalk and Sven Garmland
EMTECH elmiljöteknik ab
Box 5056, S-580 05 Linköping, Sweden

For many years, the National Swedish Power Board have studied the effects of EMP on power systems. During this work, pulse injection experiments have been carried out at two power plants, Västerås and Marviken.

The results sofar have shown that currents induced in the long overhead lines are attenuated by parts of the existing power equipment. Hereby, they are reduced to a level comparable to interference from natural sources. However, the currents and voltages induced in the control systems may be of significant importance and the threat induced close to the power plant had to be studied further.

Therefore, in the summer 1987, EMTECH carried out a CW-illumination test on an underground power plant. The purpose was to investigate the attenuation of an incident electromagnetic field which could be gained by placing a power plant under ground.

A local illumination was arranged from an antenna, terminated in the ground. A network analyser, isolated with fiber-optic links, acquired amplitude- and phase-data of the E- and H-fields. The measurements were made in the 10 kHz-100 MHz frequency range at a reference point outside and at a number of points inside the facility

After compensation for instrumentation, transfer functions were calculated. The result was confirmed by theoretical analysis and was also compared with measurements of plane waves from distant broadcast transmitters in the long-, medium- and and short-wave bands. An analytical frequency spectrum of a ground-reflected EMP and the measured transfer functions were then used to calculate fields inside the facility. The spectra were then transformed to the time-domain using the IFFT- algorithm.

The results showed that the attenuation was proportional to the frequency above approximately 1 MHz. The IFFT-calculations showed that the peak amplitude was reduced approximately one order of magnitude and that the high-frequency attenuation caused the rise-time to extend one order of magnitude. This implies that the capacitive coupling from an incident EMP would be substantially reduced by the rock.

Research sponsored by The National Swedish Power Board of Sweden.

DESIGN AND MODELLING OF A 500 kVA EMP SHIELDED TRANSFORMER

Dave Fromme, Jim Youngman, Mike Bell

Several low power audio transformer designs have been built with EMP isolation and tested. These low power transformers have had up to 100 dB of common mode rejection in the EMP frequencies of interest. At the 15 kVA power level, isolation transformers have been demonstrated with 60-80 dB attenuation in the EMP frequencies. The need for higher power efficiency in 100-500 kVA transformers while maintaining high isolation (60-80 dB of common mode signal reduction) produces conflicting requirements for the design of the next transformers. Coaxial coils with close spacings and large conductors with large areas and long lengths are necessary for high power transformer designs. These contrast with the high isolation/low power transformers which used separated coils and physical isolation of the shields on the primary and secondary.

JAYCOR has developed a computer circuit model to evaluate design options and to compare against CW and pulse tests. The model includes features designed to estimate both leakage through and around the shields and the effects of the parasitic elements. The model also is designed to provide insight and trade-off information for the coaxial coil designs which represents a large change from the low kVA design.

The modeling and test program is described in the paper. It includes detailed modeling of the coils and shielding of the 500 kVA design and will compare these results to tests of an actual engineering model of the 500 kVA transformer design.

EMP TEST RESULTS FOR ELECTRICAL DISTRIBUTION AND POWER TRANSFORMERS

C. H. Eichler
Westinghouse Electric Corporation
Advanced Systems Technology
777 Penn Center Blvd.
Pittsburgh, PA 15235

This paper presents the results of injected EMP tests on overhead distribution transformers and a power transformer. The tests were conducted at Maxwell Laboratories using a high voltage pulser capable of fast rise times. The purposes of the distribution transformer tests were to: 1) determine the effects of steep front, short duration (SFSD) surges on conventional 7.2 kV, 25 kVA, 95 kV Basic Impulse Insulation Level distribution transformers, when protected by surge arresters and when unprotected; 2) estimate the SFSD voltage levels at which these distribution transformers are likely to fail, if unprotected; 3) evaluate the effectiveness of surge arresters in protecting distribution transformers against SFSD surges; and 4) determine the failure modes of these distribution transformers. The purposes of the power transformer tests were to: 1) determine the effectiveness of surge arresters in protecting this transformer against SFSD surges; 2) determine the voltage transfer function of this transformer from primary to secondary; 3) determine the SFSD surge withstand level of this 46 kV/4.16 kV, 1500 kVA, 250 kV Basic Impulse Insulation Level substation transformer if unprotected by surge arresters; and 4) test this transformer to failure and determine the failure mode.

The results of these tests indicate that directly mounted lightning arresters can provide good protection for transformers against SFSD surges. These results are summarized and their applicability to evaluating the vulnerability of electrical power systems to SFSD surges is discussed. Recommendations are made for additional laboratory testing in this area.

*Research sponsored by the Office of Energy Storage and Distribution, United States Department of Energy, through the Martin Marietta Energy Systems, Inc., Subcontract No. 15X-43374C, for the Oak Ridge National Laboratory.

Preliminary Results of High Voltage EMP Power Filter Failure Investigation

A. Chodorow
D. Schafer
Mission Research Corp
1720 Randolph Rd, SE
Albuquerque, NM 87106

Capt H. Pohle
Air Force Weapons Laboratory
Kirtland AFB, NM 87117-6008

Following the failure of several high voltage filters, the Air Force Weapons Laboratory undertook a research program to investigate the situation. The filters were three phase units, operating at 4160/2400 volts, and designed for power throughputs of several MVA. Filters were installed on prime power feeds of large C3I facilities, to provide protection against HEMP induced transients. Filters were specified to provide on the order of 80dB attenuation over several decades of frequency. The filters were manufactured by several vendors, and installed at several locations.

Preliminary analysis indicated that in every case the capacitors, within the filters, were the elements that failed. The most likely mechanism was determined to be partial discharge taking place within capacitor insulation. A test program was conducted to evaluate various high voltage capacitors, and to compare capacitors from filter manufacturers to those used by the utility industry. The objective was to determine if commercially available power factor correction capacitors had the proper characteristics for use in filters.

Before the test program could begin, techniques for measuring partial discharges (on the order of several pico coulombs), and for placing capacitor samples under a high voltage AC load were developed. This paper describes the test techniques used to measure partial discharge, and the resonant power supply used to load and overload test samples. Temperature rise (under rated current load), self resonant frequency, equivalent resistance, and current injection tests were also performed. As a summary high voltage capacitors manufactured by filter vendors are compared to those used in the commercial power industry, and differences in manufacturing technology and qualification testing highlighted.

MEASUREMENT OF SWITCHING TRANSIENTS IN SUBSTATIONS

C. M. Wiggins, F. S. Nickel, and A. J. Haney
The BDM Corporation
1801 Randolph Road, S.E.
Albuquerque, NM 87106

Bus current transients, electric and magnetic field transients, and current transients field-coupled onto control cables produced by switching operations in 115 KV and 345 KV substations have been measured and characterized. This paper discusses similarities and differences among transients produced by different types of switching actions. We present and compare results observed from staged faults, line energizes, and when energizing and de-energizing relatively short sections of bus during disconnect switch and circuit breaker opening and closing operations. Bus current transients, caused by opening and closing disconnect switches in substations, have produced peak amplitudes as high as 680 A and 1.9 kA in 115 KV and 345 KV substations, respectively. Magnetic and electric field strength of 50-115 A/m and 9-13 kV/m, respectively, have been measured. Typically, dominant switching transient frequencies range from 0.5 MHz up to 40 MHz and are dependent on both the geometry of the line and the details of the switch. These switching transients will be compared with nominal EMP and lightning waveforms.

This work is sponsored by the Electric Power Research Institute of Palo Alto, California.

NEAR FIELD COUPLING OF SWITCHING TRANSIENTS TO SECONDARY CIRCUITS IN SUBSTATIONS

D.E. Thomas, C. M. Wiggins, III, and F. S. Nickel
The BDM Corporation
1801 Randolph Road SE
Albuquerque, NM 87106

This paper describes the preliminary results of an on-going project for the characterization, prediction, measurement, and reduction of electromagnetic interference (EMI) effects caused by routine switching operations in high-voltage electric power substations. These switching operations, which involve a variety of methods (mechanical, air blast, oil immersion, etc.) for the interruption of load current, can create high-frequency transient currents with amplitudes on the order of hundreds of amperes. As voltage levels are generally increasing for both substations and transmission systems, the magnitude of these switching transients also increases. Furthermore, the transient currents give rise to radiated electromagnetic fields which are similar to those produced by nuclear EMP; the peak electric fields can have amplitudes of several tens of kilovolts per meter, in the frequency range of 1 to 50 megahertz. Finally, the radiated fields can couple into sensor and control cables, which may be connected to sensitive microprocessor circuitry (used for monitoring of substation conditions), thus causing possible upset and/or damage.

Switching transient currents, their radiated fields, and the resultant induced control-cable transients have been both measured and predicted for a variety of situations. The measurements were obtained with a mobile EMI/EMP measurement system maintained and operated by BDM. The predictions were made with three models : METAP, TRAFIC, and CASSANDRA. Switching current transients were calculated with McGraw-Edison's Transient Analysis Program (METAP), a network analysis program developed for high-voltage power systems. The radiated fields were found from the calculated currents with the Transient Field Integration Code (TRAFIC); TRAFIC is based on a closed-form, near-field solution for radiated fields which is based on expanding current waveforms with ramp functions. Finally, induced control-cable transients were computed with the CASSANDRA code, which is an admittance-based transmission-line program.

This work is sponsored by the Electric Power Research Institute of Palo Alto, California.

SESSION 7B-1
HARDENING TECHNOLOGY: UPSET AND DAMAGE

Chairman: J. L. ter Haseborg
Technical University Hamburg-Harburg, West Germany
Thursday, 19 May (morning) Building A, Conference Room B

1 8:30 **Description of a Computer Upset Experiment (CUE) Driven with Simulated EMP**, M. S. Rickley, D. A. Nolta, J. T. Tank, and J. R. Eddleman, TRW, Redondo Beach, CA

2 8:50 **A Perspective of the Results from the Computer Upset Experiment (CUE)**, D. A. Nolta, M. S. Rickley, and J. T. Tang, TRW, Redondo Beach, CA

3 9:10 **Concepts in Upset Susceptibility of Subsystems**, R. Hanson, Booz, Allen & Hamilton, Inc., Albuquerque, NM

4 9:30 **Damage Constants for Components Based on Surge Ratings**, C. Irby, BDM Corporation, Albuquerque, NM

9:50 Coffee Break

SESSION 7B-2
HARDENING TECHNOLOGY: SYSTEM PROTECTION

Chairman: D. Serafin, Centre d'Etudes de Gramat, France
Thursday, 19 May (morning) Building A, Conference Room B

1 10:20 **Ferrite Core Saturation in Design of EMP Protection**, C. Irby, The BDM Corporation, Albuquerque, NM

2 10:40 **RF-Absorber Performance for NEMP Applications as Measured in a Novel TEM Cell**, N. Ari, D. Hansen, and H. Garbe, BBC Brown Boveri Ltd., Switzerland

3 11:00 **Integrated Electromagnetic Protection for E-6A**, G. L. Enochson, S. W. Kormanyos, and V. Severson, Boeing Aerospace, Seattle, WA

4 11:20 **NEMP Hardening of a Communication Facility**, G. K. Deb and D. C. Pande, Electronics & Radar Development Establishment, C. V. Raman Nagar, Bangalore

5 11:40 **Electromagnetic Interference and a Method of Protection from EMP**, K. R. Gottumukkala and G. S. N. Raju, Andhra University, India

1:30 Buses leave Holiday Inn for tours

9:00 AM Friday Buses leave Holiday Inn for tours

DESCRIPTION OF A COMPUTER UPSET EXPERIMENT (CUE) DRIVEN WITH SIMULATED EMP

M. S. Rickley, D. A. Nolta, J. T. Tang, J. R. Eddleman

TRW Defense Systems Group
One Space Park
Redondo Beach, CA 90278

The functional upset of a computer system due to conducted Electromagnetic Pulse (EMP) is a major concern. A functional upset is defined as a temporary interruption of system performance. The system, without manual intervention, may or may not recover. To understand this phenomenon, we investigate the upset sensitivity of a generic single board computer system. The single board computer is chosen in this first set of tests over a more intricate system because of its simpler instruction set and its reduced number of logic states.

The generic computer system utilizes the Intel 8085 microprocessor, with the following system components: Read Only Memory (ROM), Random Access Memory (RAM), programmable clock, interrupt controller, and Input/Output (I/O) handlers. This system is specially configured to be the test bed for inducing, observing and recording functional upsets. The open architecture allows the tracking of charge propagation through the system.

The approach of the upset investigation is to subject the computer board to simulated EMP transients and to characterize the resultant functional upsets. The simulated EMP transients include a double exponential, damped sinusoid, and trapezoid train. The transient is impressed onto the system as a voltage pulse between the grounds of the computer power supply and the computer board. The transient injections are synchronized to coincide with the execution of a pre-specified instruction by the computer. To capture the perturbed response in real time, we utilize a logic analyzer which outputs the circuits' timing sequences and the system's mnemonics during the event.

The induced upset can be categorized into four stages of development as the threat level increases:

(1) Glitches monitored on the processor lines.
(2) Disturbance detected at the disassembler in addition to Stage 1 observations.
(3) Error LED displays are activated in addition to Stage 2 observables.
(4) Computer operation freezes; manual re-initialization required.

We will provide examples of each of the four stages.

A PERSPECTIVE OF THE RESULTS FROM THE COMPUTER UPSET EXPERIMENT (CUE)

D. A. Nolta, M. S. Rickley, J. T. Tang

TRW Defense Systems Group
One Space Park
Redondo Beach, CA 90278

EMP induced upsets have been simulated in a specially built single board computer. Two capabilities of the pulser/instrumentation setup we designed for this study are: 1) the ability to synchronize the injection of a transient waveform with any executing program instruction, and 2) the ability to control the transient's parameters such as waveshape, amplitude and timing characteristics. These capabilities were used to gather data which allow us to parameterize functional upset and perform sensitivity studies on those parameters. The data gathered in this experiment consist of logic state, timing, oscillograph and user's observations.

Our interpretation of these data provides the following perspective in the nature of functional upset. First, the results indicate that the computer board has responded at the execution time of the targeted instruction whereas injection of the transient energy into the test setup occurred just prior to the start of the targeted instruction. A much larger delay than expected exists between the time of injection and the appearance of the system response. This delay consists of the injection delay of the instrumentation and the system delay of the active and passive components of the computer. Second, the sensitivity of the computer board to functional upset is dependent on the following parameters: 1) transient waveshape; 2) transient amplitude; 3) transient temporal characteristics; 4) computer signal line susceptibility, and 5) execution state of the computer (instruction) at the time of receipt of the transient. Third, the computer board appears to exhibit an upset "windowing" phenomenon. This phenomenon was observed by looking at the test cases where the same target command and waveshape were used but only the drive amplitude was increased. One would observe the appearance, disappearance, and reappearance of a particular glitch on a computer signal line. Fourth, to better characterize the upset response of the computer board during the transient, a probe with large differential voltage range and common mode voltage rejection is required.

CONCEPTS IN UPSET SUSCEPTIBILITY OF SUBSYSTEMS

Roy Hanson

Booz, Allen & Hamilton, Inc.
2201 Buena Vista Dr. SE
Suite 400
Albuquerque, N.M. 87106

ABSTRACT

EMP transient-induced upset susceptibility is investigated. Critical aspects of upset susceptibility are presented based upon transfer function concepts developed by Thomas (ref. 1). These constructs are modified to encompass two domains critical to understanding upset susceptibility: electrical overstress and information.

The electrical overstress domain considers the EMP-induced stress applied to the subsystem. This domain is concerned primarily with the voltages and currents induced at all levels (pin, circuit, and device) by the EMP stress, and is the domain in which the vast majority of EMP researchers operate.

The information domain is concerned primarily with processes performed using information, rather than voltages and currents, as inputs and outputs. Device level voltages and currents are interpreted by the subsystem to represent information which is operated upon by the subsystem to realize subsystem functions. In the information domain, upset occurs if:

1. Transients alter the input information.
2. Transients alter the process applied to the information.
3. Transients alter the output information.

The information domain is one in which researchers in operational effectiveness perform mission impact analyses by considering the information that the system provides in both benign and operational environments.

When upset susceptibility is considered in terms of both domains, very promising research approaches are indicated. These are:

1. Control of parasitic coupling to buried circuits: This currently uncontrolled component of the EMP stress is a major factor in mission-aborting upsets.

2. Development of Performance Norms: When a subsystem output is treated as a time function, the scalar or norm quantifiers of this function may be used as the basis for a uniform subsystem performance evaluation approach.

---

1. Thomas,R.; "Applications Of Strength/Stress Comparison Using Waveform Norm Attributes"; Analysis Of Stress Surviellance Test Data--Status Report; Kaman Sciences Corperation, Dikewood Division; p40-83; October 9 1986.

FERRITE CORE SATURATION IN DESIGN OF EMP PROTECTION

Carl Irby
The BDM Corporation
1801 Randolph Rd. SE
Albuquerque, NM 87106
(505) 848-5769

Electronic circuit component design is an integral part of hardening circuits of airborne, space, or ground-based systems to EMP. Nonlinear responses of components, such as the saturation of inductors with ferrite cores can lessen the protection they provide to EMP. This paper presents methods to evaluate and improve the effectiveness of ferrite-core inductors in mitigating EMP effects.

First, a demonstration of the effects of ferromagnetic core saturation at typical EMP frequencies was performed. The expected response of a ferrite-core inductor to a 1 microsecond pulse was calculated, assuming a constant inductance. The inductor was pulsed at one low level and two high level voltages. The inductor did not saturate at the low level as the results closely followed the calculations. However, the response of the inductor to the high level pulses indicated that saturation occured. At this point, the inductance swiftly dropped to a small value and almost the entire short-circuit current flowed through it. This demonstrates that the effectiveness of inductors in attenuating EMP effect almost completely vanishes under conditions of saturation.

Second, models were developed to predict the circuit response under saturation. Comparison with the test results validated the model. Finally, a method of evaluating circuitry containing saturable devices was developed. This paper presents this method as well as the test results described above.

RF-Absorber Performance for NEMP Applications as Measured in a Novel TEM Cell

N. Ari, D. Hansen, H. Garbe
BBC Brown Boveri Ltd.
NEMP / EMC Section
5405 Baden-Daettwil / Switzerland

New EMP threat data which include rise times of ≤ 1 ns (≥ 350 MHz) are being postulated by various researchers for EMP field generation. The characteristics of absorber at these frequencies needs to be investigated.

Some basic tests and analysis have been done, in order to help use absorbers in an optimum way. A literature survey indicates a considerable lack of applicable time domain data.

A recently developed broadband TEM cell ([1] several GHz) was used to perform field transmission, reflection and absorbtion tests. Commercially available RF absorber were used in conjunction with a fast pulse generator (50 V, 250 ps rise time). Experimental data are shown in terms of pulsed electric field attenuation for backscatter and transmission. An experiment is presented to show that absorber can act as a reradiating element. A theoretical model has been developed to determine bulk values for the relevant electrical properties of the material (complex ε and σ). Using these parameters in a transmission line model allows us to explain the measured input impedance and propagation factor of absorber, when viewed as radiating monopole antenna.

Summarizing the findings of this study, it can be concluded that the existing absorber data from manufacturers should be carefully reviewed. Future work aims at analyzing the interaction of several absorber cones acting as a phased array and the scattering from such an array.

References

[1] D. Koenigstein, D. Hansen, "A New Familiy of TEM Cell with Enlarged Bandwith and Optimized Working Volume", EMC Symposium, 1987, Zurich, Paper 24 E4, pp. 127-131

INTEGRATED ELECTROMAGNETIC PROTECTION FOR E-6A

Gail L. Enochson
Stephen W. Kormanyos
Virgene L. Severson

Boeing Aerospace Company
PO Box 3999 - Mail Stop 20-24
Seattle, WA 98124-2499

Introduction   Boeing is on contract to the Navy for up to 15 E-6A aircraft to provide survivable communications links to the ballistic missile submarine force. The contract was awarded in April 1983, CDR was held in July 1985, test flights began in June 1987, and deliveries are scheduled for 1989 thru 1990. Both FSD and production contracts are firm-fixed-price.

The E-6A has EMC, EMP, lightning, and precipitation static requirements.

EMC   Newly designed E-6A military equipments are qualified to MIL-STD-461B. Modified equipment is procured to its original specification, usually MIL-STD-461A for military equipments and DO160A for commercial equipment. A detailed, antenna coupled interference analysis was conducted to assess compatibility between the 58 antennas installed on the E-6A airframe. A ten week system level EMC test will be conducted.

EMP   The E-6A has an EMP requirement of 32 dB safety margin to upset on all mission essential equipment in all aircraft modes. A two layer aircraft hardening design has been implemented consisting of hull hardening and internal cable/cabinet shielding. A four month EMP qualification test will be conducted on the first production aircraft followed by EMP production acceptance tests on all remaining aircraft prior to delivery.

Lightning   The E-6A lightning design includes two unique features. The wing tip antenna pods use a combination of Dayton Granger transtrike lightning diverter strips and Boeing designed grounding busbars. The drogue nest assembly uses multiple ground paths via bondstraps and pulleys and other grounding points such as the exit tube assembly. Both designs have passed formal MIL-STD-1757 lightning qualification testing.

Precipitation Static   The E-6A wing tip pods also feature two unique designs for precipitation static protection. These are four static dischargers mounted on each wing pod, and the anti-static coating on the pod mounted UHF SATCOM radomes. A system level precipitation static test will be conducted.

Integrated EM Protection   We have integrated the EM disciplines on the E-6A and on all other Boeing programs having EM requirements. The EM integration on the E-6A, beginning at the outset of the program with pre-proposal work, has yielded technical and cost efficiencies in EM designs, analyses, and tests.

NEMP HARDENING OF A COMMUNICATION FACILITY

GK DEB
DC PANDE

Electronics & Radar Development Establishment
C.V. Raman Nagar, Bangalore - 560 093

Abstract

This paper deals with various NEMP hardening measures being applied to a ground based communication system facility. The nuclear electromagnetic pulse (NEMP) generated from a nuclear detonation can penetrate inside a communication facility mainly through the exterior coupling structures, such as overhead transmission lines, telephone lines, burried cables, communication antennas and their feed cables, microwave towers, waveguide feeds, ventilators and utility ducts. The NEMP coupling situation for a ground based communications facility is illustrated in Fig.1. A critical analysis of the NEMP field induced on the above exterior coupling structures of a typical communications facility / equipments shelter is presented in this paper. The effects of various NEMP control techniques applied to the individual coupling port in order to harden a communication facility/ shelter against the NEMP threat field beyond the source region are also discussed.

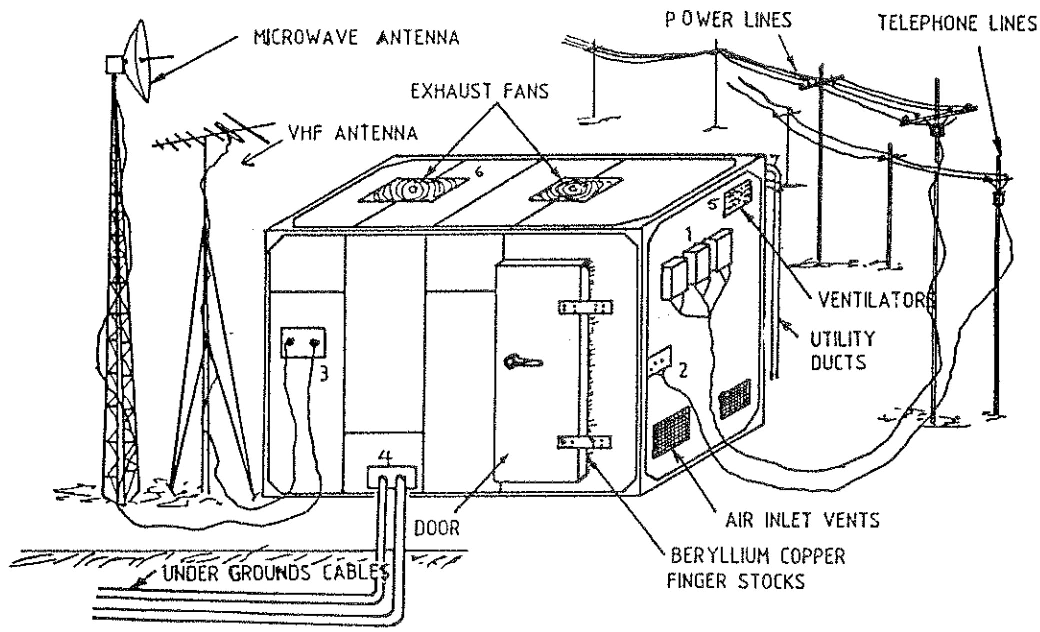


Fig. 1 : EXTERIOR NEMP COUPLING STRUCTURES IN A TYPICAL COMMUNICATION FACILITY / SHELTER

ELECTROMAGNETIC INTERFERENCE AND A METHOD OF PROTECTION FROM EMP

K.R. Gottumukkala and G.S.N. Raju
College of Engineering, Andhra University
Visakhapatnam 530 003, INDIA

ABSTRACT

Most of the electronic and communication devices are designed for general applications. Depending on their specifications, these devices are installed in different environments like ships, submarines and spacecrafts. These devices are normally tested without taking the eletromagnetic interference into account. Eletromegnetic interference (EMI) is of vital concern in the design of electronic devices. In the extreme cases, EMI can render entire system inoperative leaving the ships unable to navigate, communicate and finally susceptible to collision and virtually helpless. The important factor to escape from the problem of EMI is that the equipment must operate satisfactorily not only independently but also in conjunction with the other equipment as well. Equipment should not be adversely affected by interfering sources of energy which reach it both externally and internally.

The EMP from a nuclear detonation is dependant on the weapon burst point and location of possible affected systems. When a high yield device is detonated in the atmosphere, conversion of nuclear energy into eletromagnetic frequency spectrum takes place. The intensity of the eletromagnetic field is very high and consists of unique waveshape, because of very high intensity and unique waveform, the electromagnetic energy affects the operation of eletronic and communication equipment even at great distances. On recording the variation of eletric field strength during the burst period, it has been possible to establish a frequency spectrum using power transform technique.

Different methods of feed systems to isolate the EMP energy are reported in the literature <1>. Most of these systems act as filters for the lower frequencies which contain only a part of the EMP energy. A method of complete filtering of EMP energy is, therefore suggested in this paper. The method mainly consists of design of waveguides of appropriate dimensions to filter the interfering field frequency components. The designed rectangular waveguide dimensions and the corresponding frequencies that can be filtered are presented in a tabular form.

REFERENCES:

1. Russel V Cartensen, 'EMI Control in boats and ships' Don White Consultants Inc., 1981.

SESSION 7C

INTERACTION: EM COUPLING II

Chairman: V. Liepa, University of Michigan, Ann Arbor, MI

Thursday, 19 May (morning) Building I, Room S109

1 8:30 **A Comparison of Simple EM Coupling Models with More Complete Models**, D. F. Higgins, Santa Barbara, CA

2 8:50 **Computer Simulation of Coupling Using TLM**, P. Naylor, C. Christopoulos, P. B. Johns, University of Nottingham, UK

3 9:10 **Applications of Computer Code Macsyma for Electromagnetic Analysis**, H. Schaer, N. Ari, and H. Garbe, BBC Brown Boveri Ltd., Switzerland

4 9:30 **Bounds on Absorption Cross Section**, K. S. H. Lee, Kaman Sciences Corporation, Dikewood Division, Santa Monica, CA

9:50 Coffee Break

5 10:20 **Infrared Comparisons of the Electromagnetic Scattering from Conducting and Dielectric Cylinders**, R. M. Sega, F. J. Seiler Research Lab, and J. D. Norgard, University of Colorado, Colorado Springs, CO; M. G. Harrision, DNA, Kirtland AFB, NM

6 11:00 **Propagation of Electromagnetic Pulses over Wire Mesh Lying on Earth**, I. Kohlberg, Kohlberg Associates Inc., Alexandria, VA; F. Tesche, LuTech, Lafayette, CA

1:30 Buses leave Holiday Inn for tours

9:00 AM Friday Buses leave Holiday Inn for tours

A Comparison of Simple EM Coupling Models with More Complete Models

Daniel F. Higgins
Consultant
1040 Veronica Springs Road
Santa Barbara, CA 93105
(805) 682-5248

It is often desirable to simply and rapidly obtain estimates of EMP coupling to some system of interest. As a result, simple coupling models, many times in the form of an equivalent circuit, are often used to estimate EMP coupling. Such simple models are especially appropriate for considering electrically small 'antennas' such as a small cylinder or a short piece of cable running over a ground plane. The small cylinder can be approximated by an electrically small dipole; the open circuit voltage is then just the incident electric field times the effective height, and the capacitance of a small cylinder can be used in an equivalent circuit to calculate the short circuit current. Similarly, a short length of cable over a ground plane can be modeled by treating it as an electrically small loop driven by the changing magnetic field through the area between the loop and the ground plane.

Such simple models certainly make response estimates relatively easy to obtain, but just how accurate are such estimates, especially when the objects being considered are no longer very small compared to all wavelengths of interest ? Or, in the case of an EMP pulse with a fast risetime, just what is the waveltength of interest ? This paper will examine those questions by directly comparing time-domain results from simple equivalent circuit models with the results calculated using more accurate techniques.

For example, the current on a small cylinder predicted by an electrically small dipole model will be compared with that predicted by a finite-difference code. Cylinder size will be varied for a fixed incident field risetime, so that the situation where resonance effects first become apparent is observed. These results more accurate results will be compared to those from the circuit model so that limitations in the simpler model are apparent.

A second set of comparisons will be made using a circuit model for a cable over a ground plane and a time-domain transmission line model for the same cable. Parameters such as angle of incidence and wavefront risetime relative to cable length will be varied and the results of the two models compared. As with the small cylinder, results will be shown indicating how the response varies from a quasi-static waveform following that of the driver to one showing the characteristic resonant frequencies of the cable.

In summary, the paper will present time-domain comparisons of several simple quasi-static circuit models used to estimate EMP coupling with more accurate models which include various resonance effects. The results should help guide analysts in choosing the most appropriate models.

Computer Simulation of Coupling Using TLM

by : Dr.P. Naylor, Dr.C. Christopoulos, Professor P.B. Johns,
Department of Electrical and Electronic Engineering,
The University of Nottingham, Nottingham NG7 2RD, U.K.

Transmission-line Modelling (TLM) using a symmetrical condensed node has been used for some time for the time domain numerical simulation of surface currents on structures such as aircraft [1]. It is also suitable for analysis of interior fields [2]. More recently it has been used for calculating the coupling into single wires (a) by integrating a model of the wire into the full three-dimensional field solution, (b) by a separated solution technique, and (c) by diakoptics [3]. Developments in TLM in the modelling of wires in the integrated three-dimensional mesh will be described.

In the separated solution procedure, the fields in the vicinity of the wire are calculated with the wire removed and then TLM is used separately to calculate the propagation on the wire with various dicontinuities and loads. Clearly, certain assumptions are made. These include neglecting the effect of the wire on the fields in the three-dimensional field problem and ignoring the possibility of higher order modes propagating on the wire. In view of the usefulness of this procedure, it is important to know the conditions under which it is reasonable to make these assumptions. A standard problem of a wire in a box with an aperture and external illumination will be described, and the integrated and separated solution for wire current compared. The convergence of the two methods will be described and an attempt to give the ground rules involved will be made.

Recent work on the use of TLM for coupling into multicore cables [4] will also be briefly described.

The work is supported by a UK Ministry of Defence research agreement.

References:

1. Allen, R.A., Mallik, A., Johns, P.B. 'Numerical Results for the Symmetrical Condensed TLM Node', IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-35, No. 4, April 1987, 378-382.

2. Johns, P.B. 'Use of Condensed and Symmetrical TLM Nodes in Computer-Aided Electromagnetic Design', IEE Proceedings H, Vol. 133, Pt. H, No. 5, October 1986, 368-374.

3. Naylor, P., Christopoulos, C., Johns, P.B. 'Coupling between Electromagnetic Fields and Wires Using Transmission-Line Modelling', IEE Proceedings, Vol. 134, Pt. A. No. 8, September 1987.

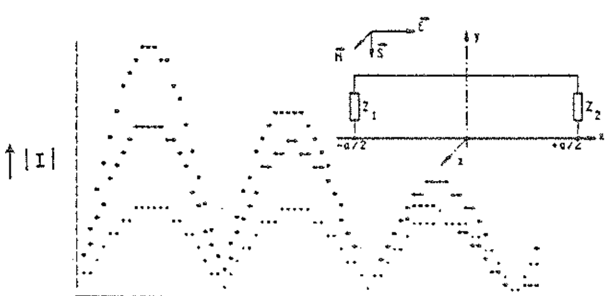
4. Christopoulos, C., Naylor, P. 'Coupling Between Electromagnetic Fields and Multiconductor Transmission Systems using TLM', accepted for publication in Issue 1 of International Journal of Numerical Modelling, January 1988.

Applications of Computer Code Macsyma for Electromagnetic Analysis

H. Schaer, N. Ari, H. Garbe
BBC Brown Boveri Ltd.
NEMP / EMC Section
5405 Baden-Daettwil / Switzerland

The purpose of this paper is to present a number of MACSYMA applications that show how the MACSYMA possibilities can be used in the field of electromagnetic applications. MACSYMA (developed by MIT) is a computer code written in LISP used for the performing symbolic and numeric mathematical manipulations [1]. Manipulations of algebraic expressions involving constants, variables, and functions can easily be done with MACSYMA. The user can differentiate, integrate, take limits, solve systems of linear or polynomial equations, expand functions in series, solve differential equations, plot curves, and manipulate matrices and tensors. It also permits the user to write programs for transforming symbolic expressions and performing algebraic simplifications. Compared with other existing approaches MACSYMA offers simpler calls of PROCEDURE's, and both easier and quicker interpretations of results. Very useful for electromagnetic applications are integrations of functions, Laplace transforms, inverse Laplace transforms, etc. [1].

Our intention is to show how the possibilities of MACSYMA are to be used for electromagnetic analysis applications. To understand the procedure easily, we first consider the well known problem of electromagnetic interaction of an incident plane wave with a transmission line. Figure 1 shows the frequency behaviour of the induced current in one of the terminating resistors for various values of the height to line length ratio.



Frequency →

Fig. 1 Magnitude of Transmission Line Current in one of the Terminating Resistors as a Function of Frequency for Various Height to Length Ratios.

As a second example an interaction with an arbitrary incident field is examined. We show how to use MACSYMA for solving an antenna problem with the method of moments [3].

References

[1] VAX UNIX MACSYMA TM Reference Manual Version 11, Nov. 1985, MIT, USA
[2] Vance E.F., Coupling to Shielded Cables, John Wiley, New York, 1978
[3] Harrington R.F., Field Computation by Moment Methods, R.E. Krieger, Florida, 1985

Bounds on Absorption Cross Section*

K.S.H. Lee
Kaman Scieces Corporation, Dikewood Division
Santa Monica, California

Absorption cross section (or effective aperture) is the best measure of coupling. It directly yields the energy or power delivered to a load, given the characteristics of the incoming wave. In this paper we first review briefly the derivation of the formulas for the absorption cross section from a field-theoretic consideration. The bounds on the cross section in the frequency and the angle-of-incidence space are then derived. Finally, we discuss how to use the absorption cross seciton to bound the EM coupling problem.

*The work was funded under Contract DNA 001-84-C-382. The Contract Technical Monitor was Mr. Gary Kwitkoski.

WITHDRAWN

INFRARED COMPARISONS OF THE ELECTROMAGNETIC SCATTERING FROM CONDUCTING AND DIELECTRIC CYLINDERS

Ronald M. Sega, F. J. Seiler Research Laboratory
US Air Force Academy, Colorado Springs, CO 80840
John D. Norgard, Department of Electrical Engineering
University of Colorado, Colorado Springs, CO 80933-7150
Michael G. Harrison, Defense Nuclear Agency, Kirtland AFB, NM 87115

There is a strong interest in the scattering properties of dielectric structures because of the roles played by wood, fiberglass and other materials which support objects being subjected to simulated NEMP or high-power microwave testing. The theory of scattering by dielectric cylinders is straightforward, but actual computations are frequently handicapped by an imprecise knowledge of the dielectric properties. In simple terms, it is of interest to determine at what frequency(ies) the scattering from wooden and fiberglass cylinders becomes too significant to ignore when taking pulsed or cw data in the RF or microwave bands. There have been analysis efforts in the past to look at specific problems such as scattering by the TRESTLE platform. There is no known experimental data which can directly confirm the analysis; again because of the lack of accurate dielctric constants and loss tangents (e.g., the real and imaginary parts of the permittivity).

An experimental effort has been performed where the field scattered from a set of conducting and dielctric cylinders has been viewed with an infrared imaging camera. Each image pixel value is related to an electric field intensity the field causes slight heating in a sheet of carbon-loaded paper placed adjacent to the scattering structure. The infrared camera is able to detect and record small differences in this heating. This process yields the electric field intensity in the plane of the detection paper. Previous studies have demonstrated the capability to view the scattered standing waves in the vicinity of a conducting circular cylinder. In this study, the fields scattered from an aluminum and wooden circular cylinder of the same dimensions (24.25" long by 11/16" radius) are compared in the frequency band 1-3 GHz. The scattering from the wooden cylinder increases dramatically between 1.2 and 1.5 GHz. The scattering from a collection of wooden and dielectric cylinders of different cross sections (1"x4", 2"x4", 4"x4", etc.) are also presented to show empirically the variation of scattering with cylinder shape. Measurements are performed with one piece of wood before and after soaking with water to demonstrate the effects of moisture. The rapid onset of significant scattering by the wooden circular cylinder between 1 and 2 GHz appears to be related to the imaginary part of the permittivity. The scattering from the wooden cylinder at and above this frequency range gives similar, but reduced in intensity, field distributions from that of the conducting cylinder. The results will be compared.

PROPAGATION OF ELECTROMAGNETIC PULSES OVER WIRE MESH LYING ON EARTH

by

Ira Kohlberg, Kohlberg Associates Inc, Alexandria, VA.
Fred Tesche, LuTech Inc, Lafayette, CA.

In this investigation we have analyzed the propagation of vertically polarized waves traveling over a mesh (in an infinite half-space) and over a wire mesh lying directly on the ground. For the mesh-only case we have been able to derive a closed-form integral relationship, expressible in terms of the Airy function, between the delivered waveform and the source waveform. As shown in Fig. #1, the response for an electromagnetic pulse exhibits quasi-periodic oscillations which can be related to the mesh parameters and distance to the field point.

Using the surface impedance concept we have been able to derive a general relationship between the surface impedance and the propagation constant in the free space over a surface. This result is used in the mesh-over-ground case. It is shown that when the skin depth into the ground is less than the wavelength in free space, the surface impedance is given by the parallel combination of ground and mesh impedance.

The results of the model are used to examine the dispersion and attenuation of an electromagnetic pulse as a function of ground conductivity, relative dielectric constant, mesh parameters, and distance. Fig. # 2 shows an example of the response; as observed, the ground provides damping of the oscillation.

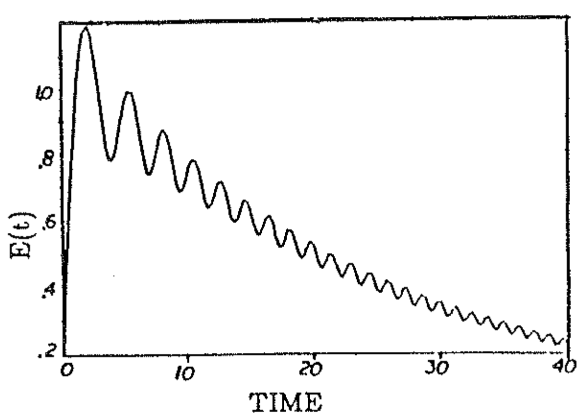


FIG 1. E(t) FOR 2″ MESH

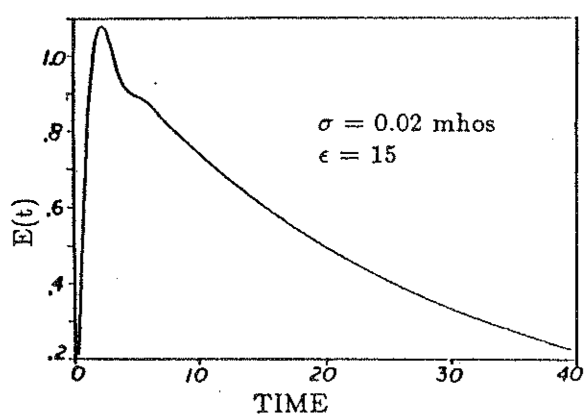
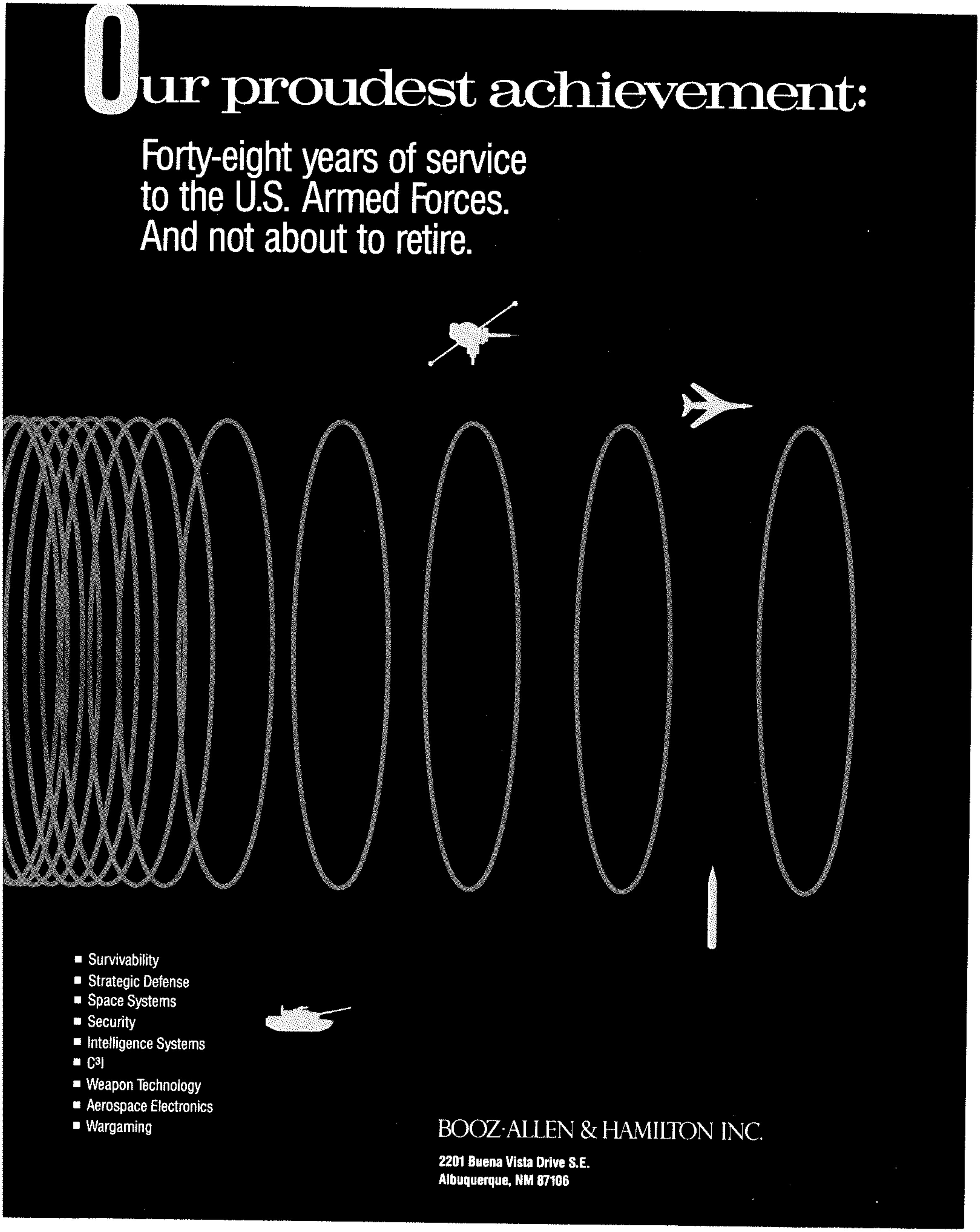


FIG 2. E(t) FOR 2″ MESH OVER GROUND

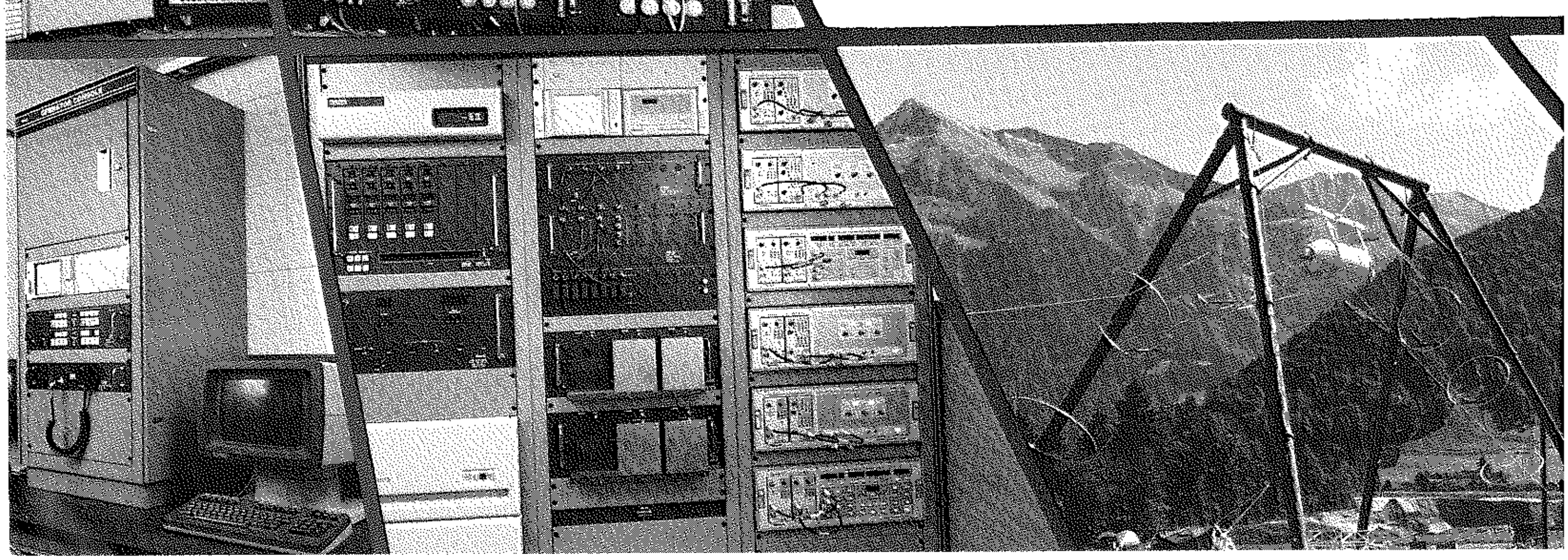

Our proudest achievement:
Forty-eight years of service to the U.S. Armed Forces. And not about to retire.
■ Survivability
■ Strategic Defense
■ Space Systems
■ Security
■ Intelligence Systems
■ C³I
■ Weapon Technology
■ Aerospace Electronics
■ Wargaming
BOOZ·ALLEN & HAMILTON INC.
2201 Buena Vista Drive S.E.
Albuquerque, NM 87106

EG&G

QUALITY EMP TEST FACILITIES AND INSTRUMENTATION . . . . . .

- Complete Line of Sensors and Probes [field, current density, current]
- Wideband Fiber Optic Data Links
- Signal Conditioners [baluns, integrators, attenuators, cable compensators, amplifiers, active signal dividers]
- Threshold Detectors, Peak Signal Recorders
- Programmable Trigger Units for Transient Recording Systems
- Inductive Current Drivers
- Automated Damped-Sine Direct-Drive Generator Systems
- Complete Data Acquisition System Design and Integration
- Complete Test Facility Design and Integration

EG&G
WASHINGTON ANALYTICAL SERVICES CENTER, Inc.,
P.O. Box 9100 Albuquerque, New Mexico 87119
[505]243-2233, TWX No. 910-989-1684, FAX No. [505]243-1021



Think About The Assignment

Then Think About The Atmosphere

Job satisfaction isn't defined by what you do from nine to five. The projects are important; the corporate philosophy is too. But the only way to keep your professional talents toned to your satisfaction is to work in an environment that tests them every day.

At General Research Corporation, you'll find assignments to think about, puzzle over and conquer. We have immediate openings in the following areas:

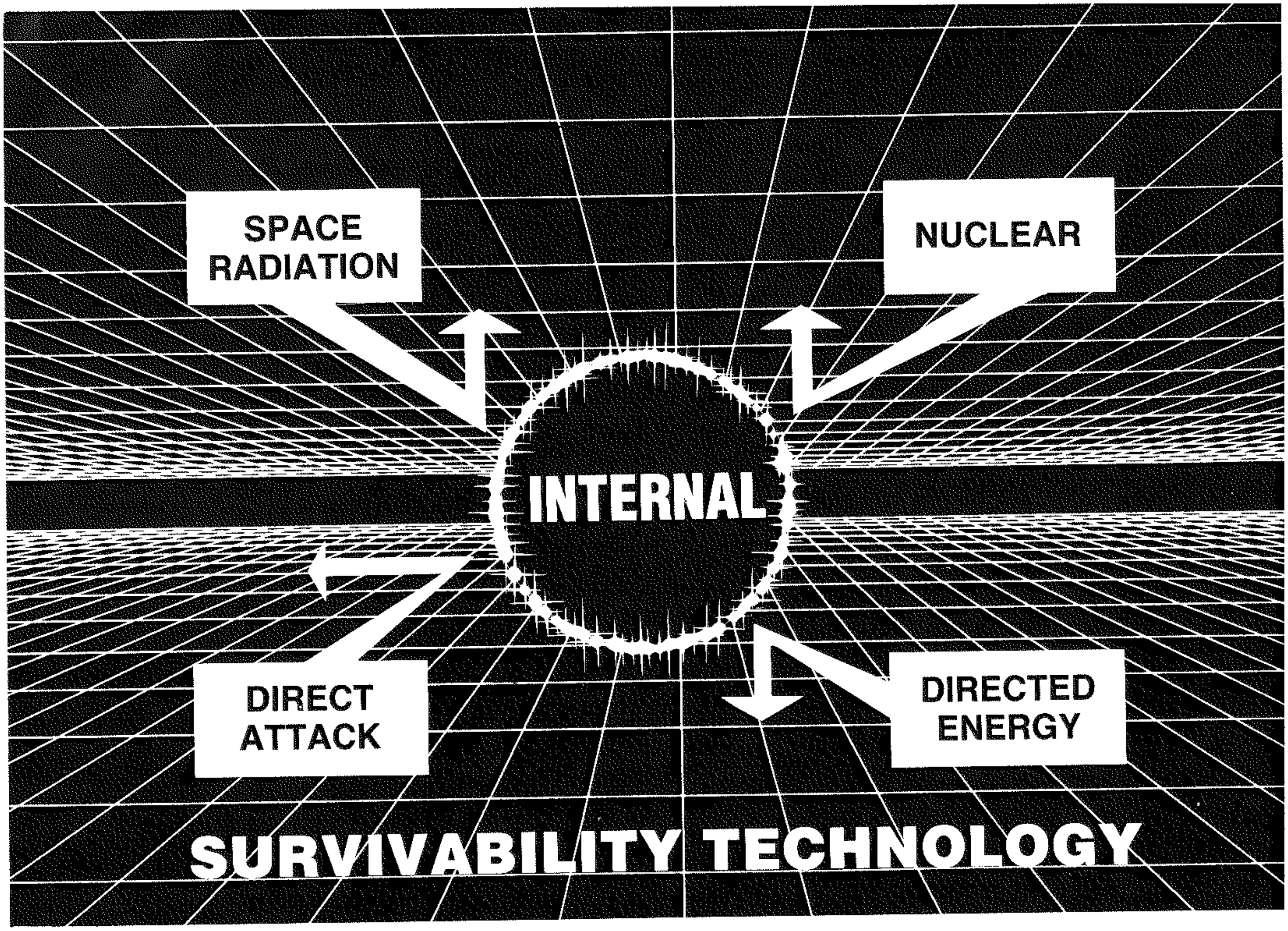
- Analysis, Evaluation and Test Planning
  - EMP/EMC/EMI
  - SGEMP
  - Mechanical and Materials Effects
- Electromagnetic Interaction and Scattering
- Assessment Methodologies
- Unique Sensor and Instrumentation Development
- Data Analysis and Signal Processing
- Threat Simulators
  - EMP
  - X - Ray
  - E - Beam
- Underground Field Testing

Outside our Santa Barbara facility, the recreational options make your off-duty hours just as satisfying. And that's something to think about.

For consideration, send your resume to: General Research Corporation, Attn: N.E. Parsons, P.O. Box 6770, Santa Barbara, CA 93160-6770. U.S. Citizenship is required. Equal opportunity is our policy and our practice. M/F/H/V.

GENERAL RESEARCH
C O R P O R A T I O N

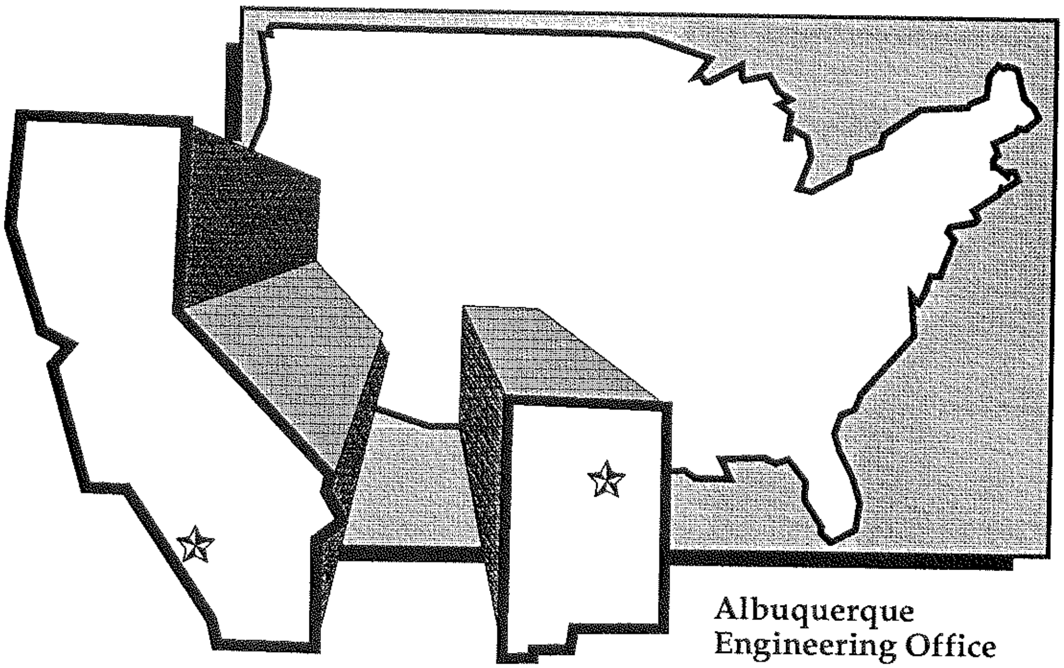
Where The Environment Is As Great As The Challenge


SPACE RADIATION
NUCLEAR
INTERNAL
DIRECT ATTACK
DIRECTED ENERGY
SURVIVABILITY TECHNOLOGY


SFS
INDUSTRIES INC.
Silicone Fabrication Specialists
EMP
SEALS AND
GASKETS
Products for Aircraft, Missiles, Ground Vehicles, Ships, Buildings, and Electrical Equipment.
Seals and Gaskets constructed to environmentally seal hatches, structural gaps, doors, and joints to provide protection from EMP.
Testing per Mil-STD-461C and Mil-G-83528
SFS Industries Inc.
13767 Freeway Drive
Santa Fe Springs CA 90670
Tel. (213) 926-6556 Fax. (213) 926-3710

TRW

A Participant in and Supporter of the NEM



Systems Engineering Ops Hqs
- Simulation and Modeling
- Systems Engineering/SETA
- Hardening Designs
- System Assessment
- Laboratory Facilities

Albuquerque Engineering Office
- Test Technology
- Data Analysis and Instrumentation
- Systems Engineering

TRW Systems Engineering Operations, an organization of over 500 people providing hardness and survivability engineering services. Our experience covers several decades and a wide range of systems. From the design of hardened spacecraft to systems engineering on ballistic missiles, from laboratory test of components to full system level EMP tests, TRW covers the spectrum of hardening technology.

For more information, contact:

Dr. Charles E. Wuller
DH4/2139
TRW
One Space Park
Redondo Beach, CA 90278

Dr. Paul Chivington
TRW
2340 Alamo S.E.
Suite 200
Albuquerque, NM 87196

A Company Called TRW

INDEX TO PRINCIPAL AUTHORS

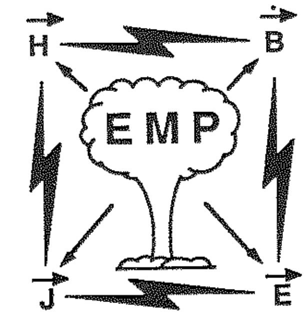
Agouridis, D. C. . . 79
Akers, G. R. 53
Ari, N. 173
Arns, D. 157
Auerbach, S. P. . 101
Baum, C. E. 27, 49, 89
Baur, D. G. 17
Beilfuss, J. 39
Bereuter, W. . . . 141
Bihua, Z. 104
Bonham, A. J. . . . 72
Borgefalk, O. . . 161
Burton, B. B. . . . 13
Butler, M. E. 74
Cabayan, H. S. . . 132
Cahoon, D. 52
Cameron, J. A. . . . 9
Casey, K. F. . 146, 149
Casper, J. 122
Catalano, P. . . . 148
Chen, K. C. . . . 113
Chen, Y. G. . . 25, 26
Cheon, C. 48
Chodorow, A. . . 164
Clark, W. T. . . . 19
Dalke, R. A. . . . 112
Davis, H. T. 70
Deb, G. K. . . . 175
Dion, M. 20
Djebari, B. . . 38, 62
Démoulin, B. . . . 43
Eichler, C. H. . . 163
Elliott, J. R. 93
Enochson, G. L . 174
Ferrero, G. . . . 151
Fromme, D. . . . 162
Garmlasnd, S. . . . 64
Giri, D. B. 60
Giri, D. V. 58
Gobin, V. 54
Gottumukkala, K. R. 176
Hansen, D. 131, 136, 140
Hanson, R. . . . 171
Herrmann, C. C. . . 91
Higgins, D. F. . . 179
Higginson, J. L. . . 5
Hoeft, C. M. 84
Hoeft, L. L. 44
Hoeft, L. O. . 109, 110,
. . 145, 82, 85, 86, 94
Ianoz, M. 80
Irby, C. 172
Jones, L. . . . 42, 83
Jurisson, K. R. . . . 69
Karlsson, T. . . . 123
Karzas, W. J. . . . 97
Kashyap, S. 15
King, R. J. 47
Koenigstein, D. . . . 73
Kohlberg, Ira . . 184
Kokorowski, S. . . 67
Kruse, K.-D. . . . 50
Labaune, G. . . . 102
Lee, K.S.H. . . . 182
Lee, Y. M. 68
Leuthäuser, K.-D. . . 98
Libelo, L. 51
Ludwigsen, A. P. . 108
Lövstrand, K-G. 138, 156
Mani, P. 141
McInerney, M. K. . . 92
Miller, P. J. . . 81, 119
Mock, G. W. . . 137
Naff, J. T. 33
Nagabhushana, G. R. 63
Nathan, P.D.R. . . 103
Naylor, P. 180
Neff, H. 4
Nickel, F. S 16
Nolta, D. A. . . . 170
Norgard, J. D. . . . 37
Oberto, G. 124
Odierno, R. T. 117, 125
Peach, D. F. . . . 118
Pennock, S. T. . . 111
Podlesny, J. J. . . . 21
Prather, W. D. 107, 155
Quinn, J. D. . . 31, 32
Radasky, W. A. . 7, 99
Rickley, M. S. . . 169
Rosenberg, Y. . . . 14
Sands, S. H. . . . 150
Schaer, H. 181
Sega, R. M. . . . 183
Shiloh, J. 129
Smith, I. . . . 59, 61
Sower, G. D. 18, 28, 57
St. John, R. H. . . . 75
Stieglitz, M. . . . 139
Taylor, C. D. . . . 90
Tesche, F. M. . . . 3
Thomas, D. E. . 6, 166
Thomas, R. . . . 121
Tolmie, B. 71
Vance, E. F. . . . 130
Vandre, R. H. . . 135
Vittitoe, C. N. . . 100
Weitze, F. M. . . . 41
Wiggins, C. M. . . 165
Williams, J. W. . . . 8
Wong, F. 120
Wright, D. B. . . 147
Zeddam, A. 40
Zuffada, C. . . 29, 30

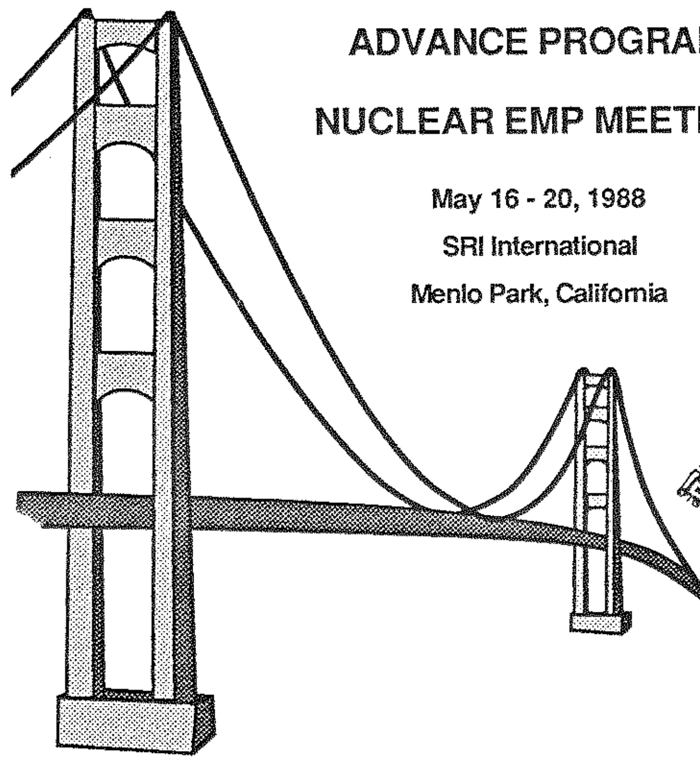
AFWL/NTAAB
Dr. Carl E. Baum
Kirtland AFB NM 87117-6008

E 10.3.88

NEM 1988 Registration
c/o Cora M. Taylor, 408-54
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

NEM 1988





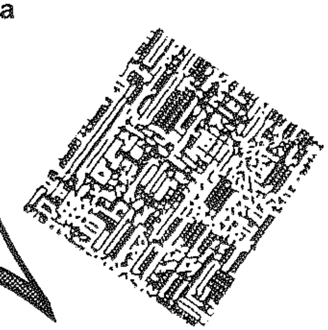
ADVANCE PROGRAM

NUCLEAR EMP MEETING

May 16 - 20, 1988

SRI International

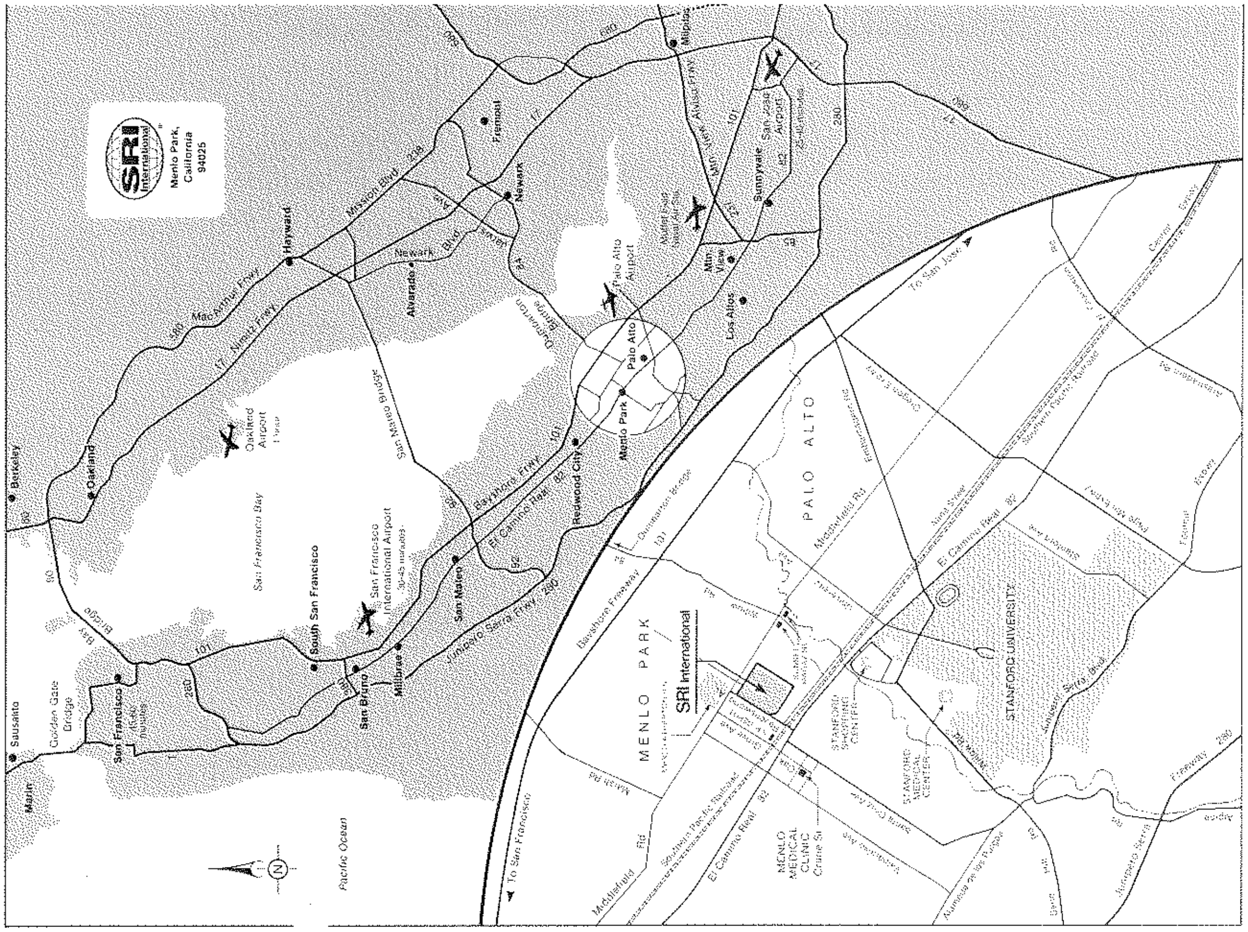
Menlo Park, California



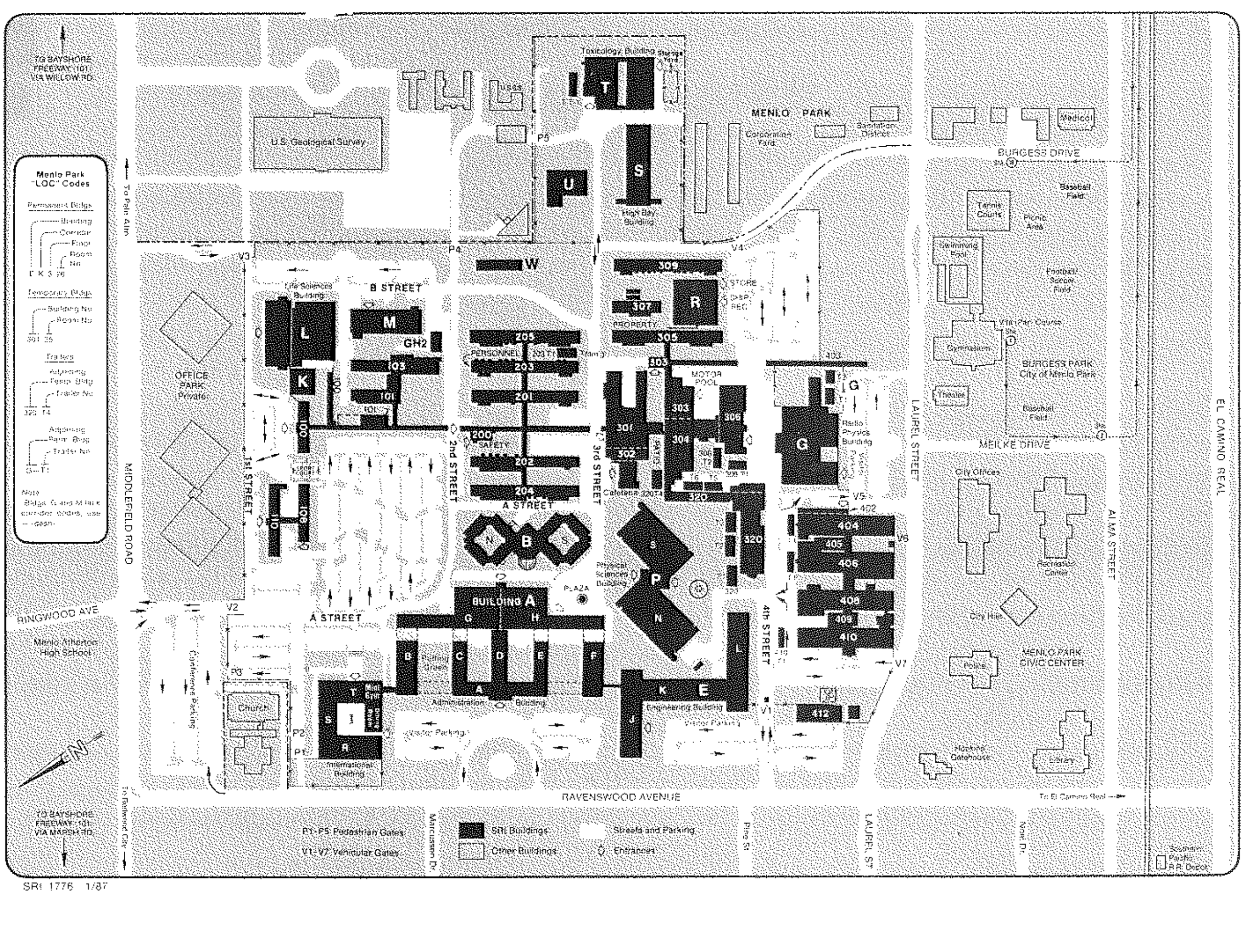
URSI

EMS

SUMMA FOUNDATION

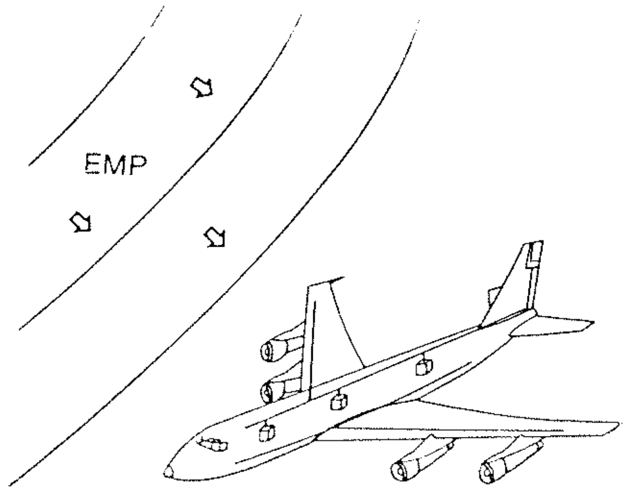


SRI International HEADQUARTERS MAP



SRI 1776 1/87

ANNOUNCING A NE WEEK COURSE ON EMP INTERACTION AND HARDENING
(EMP 201-88)



7-13 AUGUST 1988

ANN ARBOR, MICHIGAN USA

SPONSORED BY THE EDUCATION COMMITTEE OF SUMMA FOUNDATIC N

INTRODUCTION

The first six offerings of the short course (EMP 201) were given in July 1983 and August 1985 at Socorro, USA, in September 1984 at Nottingham, England, in February 1985 at Interlaken, Switzerland, in June 1986 at Yxnerum, Sweden, and in August 1987 at Karmiel,Israel. The short course was well received for both its contents and the way it was conducted. The seventh offering is now being planned and will be given in the USA.

INTENT

This course is designed to familiarize students who have a good electromagnetic background with fundamentals of EMP interaction and hardening. It will provide them with working principles and reference sources of the subject matter.

PREREQUISITES

Those who simply want to audit the course must be active in the EMP community and other related areas (such as EMC, EMI, lightning, etc.), either technically or administratively. Each of these students will receive a Certificate of Attendance at the completion of the course. Those who participate in a graduate seminar fashion during the course will each be awarded a Certificate of Achievement. The latter students must have either (a) successfully completed at least a one-year graduate EM course (on such texts as Smythe, Stratton, Jackson, Harrington, Van Bladel, Collin, Papas,Panofsky and Philips) or (b) published papers demonstrating a mastery of the material contained in those texts.

FACULTY

CARL E. BAUM received all his degrees in electrical engineering from Caltech and is currently a Senior Scientist at the Air Force Weapons Laboratory. Dr. Baum has been elected a Fellow of IEEE for poineering the Singularity Expansion Method and electromagnetic topology in electromagnetic theory, and for development of EMP simulation and electromagnetic sensors. He has previously been appointed a Distinguised Lecturer of the Antennas and Propagation Society of the IEEE, and is a member of Commissions B and E of the U.S. National Committee of URSI and a former President of the Electomagnetics Society. In October 1984 Dr. Baum received the Richard R. Stoddart Award from the IEEE EMC Society "for service as the scientific organizer and editor of EMP technical publications." In January 1987 he was awarded the Harry Diamond Memorial Award by the IEEE Board of Directors "for outstanding contributions to the knowledge of transient phenomena in electromagnetics."

Dr. Baum has assembled a team of distinguished faculty members from leading EMP experts in USA and Europe. Past faculty members include K.F. Casey, J.P. Castillo, S.H. Gurbaxani, R. L. Gardner, D. V. Giri, W. Graf, M. Ianoz, P.B. Johns, T. Karlsson, K.S.H. Lee, L. Marin, C.D. Taylor, F. M. Tesche, and E.F. Vance.

DAILY SCHEDULE

SUNDAY/AUGUST 7
After arrival, registration and dinner, Sunday evening will be devoted to the introduction of students, familiarization with course outline and what is expected in the course.

MONDAY/AUGUST 8
The faculty will lecture on the fundamentals of EMP interaction. This is related to Part I of the text (EMP Interaction: Principles, Techniques and Reference Data). Assignments for future classes will be given out at the end of the day. The evening after dinner will be devoted to informal discussion and lecture preparation.

TUESDAY THROUGH THURSDAY/AUGUST 9-11
Faculty members will lecture about one hour at the start of each morning and afternoon session on selected aspects of EMP interaction. Students will give mini-lectures, about 15 minutes each, on material assigned by the faculty. Each evening after dinner will follow the Monday schedule of informal discussion and lecture preparation.

FRIDAY/AUGUST 12
The lectures are in part devoted to material from Part III of the text, including hardening techniques and system example problems. Friday evening will be reserved for banquet and certificate award.

SATURDAY/AUGUST 13
The course will be concluded after breakfast.

COURSE MATERIAL

EMP Interaction: Principles, Techniques and Reference Data,Hemisphere Publishing Corp., New York, 1986.

Special Joint Issue on the Nuclear Electromagnetic Pulse:IEEE Trans. Antennas Propagat., Vol. AP-26, January 1978, and also IEEE Trans., Electromagn. Compat.,Vol. EMC-20, February 1978.

Special Issue on Electromagnetic Topology of Large Systems: Electromagnetics, Vol. 6, No.1, 1986.

GENERAL INFORMATION

LOCATION

The site selected for the course is Ann Arbor, Michigan, USA. Further details concerning transportation will be mailed to students.

FEE

The fee per student is 950 dollars in U.S. currency, which includes tuition, lodging, meals, and course materials.

ENROLLMENT

Early enrollment is recommended since the class is limited to FORTY students. Full fee must accompany the application, although reservations may be made by telephone for those requiring time to obtain authorization. However, reservations should be confirmed FOUR weeks in advance of the course starting date. After this time, applications accompanied by full fee will be given priority. Those desiring to enroll after this should first verify that space is available.

Contact the following:

Reservations and Registration	Information
Prof. Valdis Liepa or Leah Allen (Secretary) University of Michigan/EECS 3242 EECS Building 1301 Beal Ave. Ann Arbor, Michigan 48109 Telephone: (313) 764-0500	Dr. C.E. Baum 5116 Eastern, S.E., Unit Albuquerque, New Mexico 87108 Telephone: Work: (505) 844-9816 Home: (505) 265-9479

REFUNDS

The course fee will be refunded if cancellation of enrollment is received ONE week before the first day of the course.The course organizers should be notified immediately by telephone (see number above) followed by a written request for refund.

ENROLL NOW BY MAIL using the form on the reverse side. A tentative telephone registration can also be made by calling Prof. V. Liepa or Leah Allen.

ENROLLMENT FORM

EMP Interaction and Hardening
(EMP 201-88)
7-13 August 1988
Fee: $950 in U.S. currency

Name ____________________

Organization ____________________

Address ____________________

____

Telephone ____________ Telex ____________

Brief descriptions of EMP and/or related activities ____________________

____

____

Type of student: ☐ Auditing ☐ Participating ☐ Either

Enclosed find: ☐ Check for full payment ☐ Purchase Order ☐ Billing Authorization
☐ International Money Order for full payment

Please make check payable to "EMP 201-88" along with qualifications such as reprints of published papers/reports or transcripts, and mail to Prof. Liepa. Full fee will be refunded to non-qualified applicants.

____
Signature

(This can be photocopied)