NEM 1986 RECORD

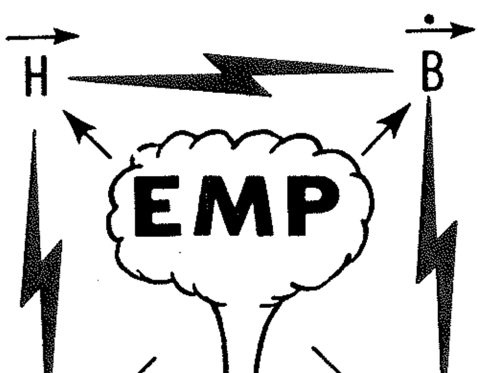
ABSTRACTS OF TECHNICAL PAPERS

Nuclear EMP Meeting

May 19-23, 1986

University of New Mexico

Albuquerque, New Mexico



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LOCATION	MAY 19 MONDAY 8:30 - 12:00	MAY 19 MONDAY 1:30 - 5:00	MAY 20 TUESDAY 8:30 - 12:00	MAY 20 TUESDAY 1:30 - 5:00	MAY 21 WEDNESDAY 8:30 - 12:00	MAY 21 WEDNESDAY 1:30 - 5:00	MAY 22 THURSDAY 8:30 - 12:00	MAY 22 THURSDAY 1:30 - 5:00	MAY 23 FRIDAY
EDUCATION CENTER, ROOM 101	101-1A MICROCOMPUTER APPLICATIONS: GRAPHICS/ HARDWARE/ SOFTWARE 101-1B MICROCOMPUTER APPLICATIONS: SIGNAL PROCESS-ING, EXPERT SYSTEMS & CAD	101-2A MICROCOMPUTER APPLICATIONS: ELECTROMAGNETIC MODELING 101-2B MICROCOMPUTER APPLICATIONS: CIRCUIT ANALYSIS 101-2C PANEL DISCUSSION	101-3 NEW EMP PROGRAMS	101-4 EMP & ELECTRIC POWER SYSTEMS: PANEL	P1 PLENARY SESSION STUDENT UNION BALLROOM	101-6 EMP ENVIRONMENTS & SOURCE-REGION EFFECTS	101-7A LIGHTNING 101-7B LIGHTNING: PANEL	101-8A STANDARDS & SPECIFICATIONS 101-8B STANDARDS & SPECIFICATIONS PANEL	T O U R S MAY 18 SUNDAY **REGISTRATION RECEPTION,** HILTON HOTEL, 6 - 10 p.m.
EDUCATION CENTER, ROOM 103	103-1A SIMULATION FACILITIES 103-1B DIRECT DRIVE SIMULATION	103-2 SUBSYSTEM HARDENING	103-3 ASSESSMENT OF EMP EFFECTS ON POWER SYSTEMS	103-4 SIMULATION		103-6 HARDNESS SURVEILLANCE/ MAINTENANCE	103-7 BOUNDED WAVE SIMULATORS	103-8 DATA ACQUISITION	DAILY, MONDAY TO THURSDAY: **REGISTRATION** Courtyard of Education Complex 8a.m.-4p.m.
EDUCATION CENTER, ROOM 104	104-1 EXTERNAL INTERACTION	104-2 HEMP INTERACTIONS WITH OVERHEAD POWER LINES	104-3 SEM: EMPHASIS ON DATA ANALYSIS	104-4 RESPONSE OF ELECTRONIC PARTS		104-6 TRANSMISSION-LINE NETWORKS	104-7 INTERNAL INTERACTION	104-8 APERTURES	
EDUCATION CENTER, ROOM 105	105-1A SUBSYSTEM HARDENING-CABLES 105-1B SUBSYSTEM HARDENING DEVICES	105-2 SENSORS AND DATA PROCESSING	105-3 MICROCOMPUTER DEMONSTRATIONS	105-4 MICROCOMPUTER DEMONSTRATIONS		105-6 PROBABILITY ISSUES AND HARDNESS VERIFICATION	105-7 SYSTEM HARDENING		

BIENVENIDOS
A
ALBUQUERQUE

On behalf of the conference committee, the Permanent NEM Committee of SUMMA Foundation, the Department of Electrical Engineering and Computer Science of the University of New Mexico, and the cooperating professional and governmental groups, I would like to welcome all the conference attendees to NEM 1986. I would particularly like to thank the conference committee for all the hard work they have done to make NEM 86 a successful conference.

The purpose of the NEM series of conferences is to be a wide-ranging forum covering the entire spectrum of nuclear EMP related technology. The selection of papers submitted to NEM 86 certainly supports that goal. In addition to the usual NEM topics, there are three sessions on microcomputer applications and panels on lightning, microwave applications, power systems, and standards and specifications. The nearly two hundred papers that make up the conference should provide technical stimulation for all attendees.

The social program should also provide a means for the attendees to enjoy the facets of New Mexico life. There are tours to explore both the technical facilities of the New Mexico area and interesting tourist attractions. The Awards Banquet is the central social event, but there are business meetings and mixers to help renew old friendships and begin new ones.

I wish all of you a most productive and memorable conference.

Dr. Robert L. Gardner
Conference Chairman

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- Commission B: Fields and Waves
- Commission E: Noise and Interference Environment

Electromagnetics Society

University of New Mexico

Air Force Office of Scientific Research

Air Force Weapons Laboratory

Army Research Office

Harry Diamond Laboratories, Naval Surface Weapons Center

Office of Naval Research

PLENARY SESSION
WEDNESDAY, MAY 21, 8:30-12:00
STUDENT UNION BALLROOM

Chairman: L.F. Libelo
Harry Diamond Laboratories
Adelphi, Maryland

SESSION 101-1A
MONDAY, MAY 19, 8:30-10:10
EDUCATION CENTER, ROOM 101

MICROCOMPUTER APPLICATIONS
Graphics/Hardware/Software

Chairman: R.L. Hutchins
The BDM Corporation
Albuquerque, New Mexico

SESSION 101-1B
MONDAY, MAY 19, 10:40-12:00
EDUCATION CENTER, ROOM 101

MICROCOMPUTER APPLICATIONS
Signal Processing, Expert Systems and CAD

Chairman: R.L. Hutchins
The BDM Corporation
Albuquerque, New Mexico

SESSION 103-1A — SIMULATION FACILITIES

MONDAY, MAY 19, 8:30-10:10

EDUCATION CENTER, ROOM 103

Chairman: B. Des Vergnes
Centre Essai des Landes (CEL),
France

SESSION 103-1B — DIRECT DRIVE SIMULATION

MONDAY, MAY 19, 10:40-12:00

EDUCATION CENTER, ROOM 103

Chairman: M.G. Harrison
Defense Nuclear Agency
Albuquerque, New Mexico

SESSION 104-1 **EXTERNAL INTERACTION**
MONDAY, MAY 19, 8:30-12:00
EDUCATION CENTER, ROOM 104

Chairman: **R.G. Joiner**
Office of Naval Research
Washington, D.C.

		Page
1 8:30	**Analytic Extension of Frequency Domain Thin Wire Antenna EMP Currents to a Three Dimensional Aircraft Model,** R.W. Sutton and D.G. Edelman, Science Applications International Corporation, McLean, VA	24
2 8:50	**Numerical Solution to Maxwell's Equations with Non-Orthogonal Grids,** K.S. Yee, Lawrence Livermore National Laboratory, Livermore, CA	25
3 9:10	**The Use of Transmission-Line Modelling (TLM) in External Interaction Problems,** C.S. Smerdon and J.M. Thomson, Royal Aircraft Establishment, Farnborough Hants, UK; and T.W. Armour, Kimberley Communications Consultants, Nottingham, UK	26
4 9:30	**Direct Time-Domain Calculation of the Radiated Fields Due to Current Transients,** D.E. Thomas and R.L. Hutchins, The BDM Corporation, Albuquerque, NM	27
5 9:50	**Coupling of a Plane Wave to a Square Metal Plate,** L.F. Libelo and F.S. Libelo, L and L Associates, Bethesda, MD; and C.L. Andrews, State University of New York, Albany, NY	28
10:10	Break	
6 10:40	**A Model to Predict the Electromagnetically Induced Currents on a Cylinder Plus Single Wire,** L.W. Jacobi, The MITRE Corporation, Bedford, MA	29
7 11:00	**Responses of F-106B to Simulated Electromagnetic Pulse (EMP),** F.C. Yang and K.S.H. Lee, Dikewood Division of Kaman Sciences Corporation, Santa Monica, CA	30
8 11:20	**Measurement Methods of Earth Systems Impedance at Lightning and EMP Frequencies,** F. Paladian and D. Le Fevre, Les Cables de Lyon - HF Division, Bezons, France	31
9 11:40	**Electromagnetic Coupling to Conductors with Helical Geometry,** G.L. Duerksen, AT&T Bell Laboratories, Holmdel, NJ	32

SESSION 105-I SUBSYSTEM HARDENING
MONDAY, MAY 19, 8:30-12:20
EDUCATION CENTER, ROOM 105

Chairman: P. Parhami
TRW
Redondo Beach, California

SESSION 101-2A
MONDAY, MAY 19, 1:30-3:10
EDUCATION CENTER, ROOM 101

MICROCOMPUTER APPLICATIONS
Electromagnetic Modeling

Chairman: E.K. Miller
University of Kansas
Lawrence, Kansas

SESSION 101-2B
MONDAY, MAY 19, 3:40-4:20
EDUCATION CENTER, ROOM 101

MICROCOMPUTER APPLICATIONS
Circuit Analysis

Chairman: R.L. Hutchins
The BDM Corporation
Albuquerque, New Mexico

SESSION 101-2C
MONDAY, MAY 19, 4:20-5:30
EDUCATION CENTER, ROOM 101

MICROCOMPUTER APPLICATIONS FOR EMP
Panel Discussion

This panel will discuss the role and utility of microcomputers for EMP design and analysis.

TOPICS: Capabilities and Limitations
- Hardware and Software
- Micros versus Minis and Mainframes
- Increased Efficiency or a Time Sink
- Increased Technical Literacy versus Garbage In/Garbage Out

Chairman: R.L. Hutchins, The BDM Corporation

Panelists: D.F. Higgins, JAYCOR
E.K. Miller, University of Kansas
F.M. Tesche, LuTech, Inc.

SESSION 103-2 **SUBSYSTEM HARDENING**
MONDAY, MAY 19, 1:30-4:40
EDUCATION CENTER, ROOM 103

Chairman: **D. McLemore**
Kaman Sciences Corporation
Colorado Springs, Colorado

SESSION 104-2 HEMP INTERACTION WITH OVERHEAD POWER LINES
MONDAY, MAY 19, 1:30-5:20
EDUCATION CENTER, ROOM 104

Chairman: K.S.H. Lee
Kaman Sciences Corp., Dikewood Division
Santa Monica, California

SESSION 105-2 **SENSORS AND DATA PROCESSING**
MONDAY, MAY 19, 1:30-5:20
EDUCATION CENTER, ROOM 105

Chairman: **G. Sower**
EG&G
Albuquerque, New Mexico

SESSION 101-3
TUESDAY, MAY 20, 8:30-12:00
EDUCATION CENTER, ROOM 101

NEW EMP PROGRAMS

After a brief presentation by the panelists concerning EMP requirements of their country or organization, the session will be open for comments and discussion by all attendees.

Chairman: D. Giri
Pro-Tech and University of California/Berkeley

Panelists: P. Agaard, Posts and Telegraphs, Denmark

G.K. Deb, Defence Research and Development Organization, India.

D. Hansen, Brown, Boveri and Company, Switzerland

J. Quinn, Department of Defence, Australia

B. Young, Defense Research Establishment, Canada

SESSION 103-3 ASSESSMENT OF EMP EFFECTS ON POWER SYSTEMS
TUESDAY, MAY 20, 8:30-12:20
EDUCATION CENTER, ROOM 103

Chairman: P.R. Barnes
Oak Ridge National Laboratory
Oak Ridge, Tennessee

SESSION 104-3 SEM: EMPHASIS ON DATA ANALYSIS
TUESDAY, MAY 20, 8:30-12:00
EDUCATION CENTER, ROOM 104

Chairman: M.L. Van Blaricum
General Research Corporation
Santa Barbara, California

SESSION 105-3
TUESDAY, MAY 20, 8:30-12:00
EDUCATION CENTER, ROOM 105

MICROCOMPUTER DEMONSTRATIONS

Organizer: R.L. Hutchins
The BDM Corporation
Albuquerque, New Mexico

SESSION 101-4 — **EMP AND ELECTRIC POWER SYSTEMS: PANEL DISCUSSION**

TUESDAY, MAY 20, 1:30-4:00
EDUCATION CENTER, ROOM 101

The Department of Energy (DoE) is sponsoring a research program to assess the impact of EMP on electric power systems. This program is attempting to develop appropriate hardware and procedures for enhancing the reliability of electric power systems subject to EMP environments. The assessments will also be used to develop procedures for fast restoration of power in the event of EMP caused outages. The following questions will be addressed:

- Given the complexity of the electric power system, is it feasible to perform an assessment which will develop appropriate hardware and procedures for limiting damage to critical components? For enhancing restoration? Why or why not?

- In either case, what actions are appropriate for limiting damage to critical components of the power systems? Is it appropriate to take such actions or should a do nothing attitude be the preferred approach?

- Should there be additional studies to assess the impact of EMP on communications and data systems? On other large networks?

Chairman: B.W. McConnell, Oak Ridge National Laboratory

Panelists: H.W. Colborn, NERC
W.J. Karzas, R&D Associates
T.J. Reed, Westinghouse
E.F. Vance, EMP Consultant
D.R. Volska, WEPCO
M. Wik, FMV, Sweden

SESSION 103-4 SIMULATION
TUESDAY, MAY 20, 1:30-4:20
EDUCATION CENTER, ROOM 103

Chairman: T. Ruedy
Armament Technology and Procurement Group
Spiez, Switzerland

SESSION 104-4 RESPONSE OF ELECTRONIC PARTS
TUESDAY, MAY 20, 1:30-4:40
EDUCATION CENTER, ROOM 104

Chairman: T. Flanagan
JAYCOR
San Diego, California

SESSION 105-4
TUESDAY, MAY 20, 1:30-5:00
EDUCATION CENTER, ROOM 105

MICROCOMPUTER DEMONSTRATIONS

Organizer: R.L. Hutchins
The BDM Corporation
Albuquerque, New Mexico

SESSION 101-6 EMP ENVIRONMENTS & SOURCE-REGION EFFECTS
WEDNESDAY, MAY 21, 1:30-2:10
EDUCATION CENTER, ROOM 101

Chairman: W.A. Radasky
Metatech
Goleta, California

SESSION 103-6 **HARDNESS SURVEILLANCE/MAINTENANCE**
WEDNESDAY, MAY 21, 1:30-5:20
EDUCATION CENTER, ROOM 103

Chairman: **W. Brummer**
Air Force Weapons Laboratory
Kirtland AFB, New Mexico

SESSION 104-6 TRANSMISSION-LINE NETWORKS
WEDNESDAY, MAY 21, 1:30-4:20
EDUCATION CENTER, ROOM 104

Chairman: P. Johns
University of Nottingham
England

SESSION 105-6 **PROBABILITY ISSUES AND HARDNESS VERIFICATION**
WEDNESDAY, MAY 21, 1:30-2:10
EDUCATION CENTER, ROOM 105

Chairman: **J. Locasso**
Rockwell International
Anaheim, California

SESSION 101-7A — **LIGHTNING**

THURSDAY, MAY 22, 8:30-10:10

EDUCATION CENTER, ROOM 101

Chairman: **J.E. Nanevicz**
SRI International
Menlo Park, California

10:10 Break

SESSION 101-7B — **LIGHTNING: PANEL DISCUSSION**

THURSDAY, MAY 22, 10:40-12:00

EDUCATION CENTER, ROOM 101

The panel discussion on lightning will include descriptions of the state of the art in the following research areas: measurement of electromagnetic parametrs of lightning, modeling of stroke currents and radiated fields, simulation of lightning for aircraft testing, comparisons of lightning and EMP effects on systems, unification of specifications and standards for lightning and EMP, and measurement of responses of aircraft in flight to lightning environment.

Chairman: J.E. Nanevicz, SRI International

Panelists:
R. Gardner, Mission Research Corporation
C. Moore, New Mexico Institute of Technology
S. Schneider, Boeing Aerospace
J. Taillet, ONERA
M. Uman, University of Florida
E. Vance, SRI International
L. Walko, USAF, WPAFB

SESSION 103-7 **BOUNDED WAVE SIMULATORS**
THURSDAY, MAY 22, 8:30-10:10
EDUCATION CENTER, ROOM 103

Chairman: W. Petty
Harry Diamond Laboratories
Adelphi, Maryland

SESSION 104-7 INTERNAL INTERACTION
THURSDAY, MAY 22, 8:30-10:30
EDUCATION CENTER, ROOM 104

Chairman: K.F. Casey
JAYCOR
Fremont, California

SESSION 105-7 **SYSTEM HARDENING**
THURSDAY, MAY 22, 8:30-11:20
EDUCATION CENTER, ROOM 105

Chairman: M. Wik
Forsvarets Materielverk
Stockholm, Sweden

SESSION 101-8A — STANDARDS & SPECIFICATIONS (CONT'D)
THURSDAY, MAY 22, 1:30-2:10
EDUCATION CENTER, ROOM 101

Chairman: W. Prather
Air Force Weapons Laboratory
Kirtland AFB, New Mexico

SESSION 101-8B — STANDARDS & SPECIFICATIONS: PANEL
THURSDAY, MAY 22, 3:40-5:00
EDUCATION CENTER, ROOM 101

OBJECTIVES: Provide forum for discussion of subjects pertinent to Specifications and Standards:

- Status of Current Programs
- Standards & Specifications Systems Applications Allocation
- Relation to EMI/EMC, lightning and TEMPEST Standards and Specifications
- Verification Procedures, Techniques
- Special Needs, Direction for Future Research

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

Panelists:
D. Baseley, Aeronautical Systems Division
J. Bishop, RAE, United Kingdom
D. Butts, Joint Chiefs of Staff
B. Cikotas, Defense Communications Agency
L. Marin, Kaman Sciences, Dikewood Division
G. Morgan, Rockwell International
W. Petty, Harry Diamond Laboratories
Maj. M. Hoke, Defense Nuclear Agency
W. Prather, Air Force Weapons Laboratory
H. Smith, USN
E.F. Vance, SRI International

SESSION 103-8 **DATA ACQUISITION**
THURSDAY, MAY 22, 1:30-3:30
EDUCATION CENTER, ROOM 103

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

SESSION 104-8 APERTURES
THURSDAY, MAY 22, 1:30-4:40
EDUCATION CENTER, ROOM 104

Chairman: R.J. King
Lawerence Livermore National Laboratory
Livermore, California

A Survey of Instrumentation for EMP Related Measurements

J.C.Giles, J.R.Pressley, and G.D.Sower
EG&G Washington Analytical Services Center, Inc.
P.O.Box 9100
Albuquerque, N.M. 87119

A brief survey of the state of the art in EMP instrumentation is presented starting with the sensors and probes used to measure electromagnetic quantities of interest and following the signal path through the measurement chain to the recording and data analysis equipment and software. The elements covered are as follows: sensors and probes, signal conditioners, fiber optic telemeter links, data recorders, on-line data processing and analysis, and finally system integration. At each step in the measurement chain examples of currently available equipment are described and compared.

The paper primarily describes data acquisition for system-level pulse illumination testing, but a few examples of continuous wave (CW) systems are discussed. Obviously many of the elements are useful in subsystem-level direct drives test as well.

The final section briefly describes the task of putting all the pieces -- hardware and software -- together into an integrated instrumentation system and gives examples of complete EMP data acquisition systems developed by several government agencies and contractors.

ELECTRIC ENERGY SYSTEMS RESEARCH PROGRAM*

Kenneth W. Klein
Department of Energy
Office of Energy Storage and Distribution
Forrestal Building, Mail Stop 5E-052
Washington, D.C. 20585

ABSTRACT

The Department of Energy's Electric Energy Systems Research Program was formulated to provide technology options that will enhance the reliability of the nation's future electric energy supply, improve the efficiency of electric energy systems, and determine biological health effects of high voltage electric fields. The program is divided into three broad areas of research: Electric Field Effects, Systems Technology, and Reliability. Electric field effects research consists of biological studies, risk analysis, and analysis of ion effects associated with high voltage dc lines. Systems technology research includes studies on new materials for insulators and arrestors, automation and load leveling technology development, and other systems related to research and development. Reliability research includes the EMP program area, emergency operation concepts, and analysis of failure mechanisms.

The objectives for the Electromagnetic Pulse (EMP) program area are to assess the effects of EMP on electric power systems and to recommend hardening hardware and procedures as necessary to enhance the reliability of our electric energy supply to intense electromagnetic disturbances. The goal is to increase national security by improving the reliability of electric energy systems subject to the EMP environment. An overview of the Electric Energy Research Program and selected projects in the EMP area and other programs areas will be presented.

*Research sponsored by the Office of Energy Storage and Distribution, Electric Energy Systems Program, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

STANDARDIZATION OF EMP HARDENING REQUIREMENTS

Edward F. Vance
SRI International, Inc.
333 Ravenswood Avenue
Menlo Park, California 94025

ABSTRACT

The standardization of EMP hardening requirements is needed to support procurement of military systems that are immune to this nuclear weapon effect. Several efforts are under way to develop system hardening standards. This paper discusses some of the interesting paradoxes in standardizing EMP hardening.

Standardization of EMP hardening implies that it is possible to harden systems. Although it is generally presumed that hardening is possible, we have little experience upon which to base this presumption. No U.S. system built since 1962 has been exposed to the environment produced by an atmospheric or high altitude detonation of a nuclear weapon. Thus faith in our ability to harden cannot come from experience with the systems in nuclear environments; it must be developed by indirect means. It is interesting to contrast this situation with that of some of the more mature technologies, where extensive testing in actual operating environments does not prevent occasional premature, unforeseen failures.

It is also presumed that we can determine whether or not a system has been hardened. As noted above, we are unable to test systems in the environment produced by a nuclear weapon; we must use analytical and experimental means to assess the system's immunity to the effects of nuclear weapons. Modern systems are very complex, electromagnetically, and the EMP is a high amplitude, broad spectrum transient. All analyses require estimates of electromagnetic properties of materials (many of which are uncontrolled) and approximations of the system configurations, and all experimental simulations are imperfect in one or more aspects. Hence sufficient understanding of the interaction of the EMP with the system to conclude that the effect of the EMP is benign may be achieved only if the hardening design facilitates the assessment.

The investment in EMP hardening has value only if the hardening can be maintained. System hardness must be sufficiently durable that normal use, maintenance, and system growth and evolution do not degrade EMP hardness. Furthermore, system hardness must be easy enough to assess that it can be frequently and economically re-evaluated throughout the life of the system.

Estimating Vulnerability to Electromagnetic Pulse Effects*

JOHN M. RICHARDSON, National Academy of Sciences-National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418

Estimation of vulnerability to high-altitude electromagnetic pulse (EMP) effects is essential for strategic and tactical decisions affecting national security. Both the design and the assessment of protection against EMP are inherently subject to uncertainty. The reason is that these processes must be conducted without exposure to actual EMP, in contrast to the situation for other forms of electrical overstress. Estimating vulnerability of systems to EMP effects depends greatly on the nature of the system. The soundest results can be obtained where stress within the system is controlled, through integral shielding and penetration-control devices, to well known values. In this case, one can rely on engineering analysis and systematic testing of a predominantly deterministic nature. Where control and knowledge of stress, as well as of strength, are not possible because of system design, complexity, or uncontrolled changes, probabilistic estimates become necessary. Statistical methods for estimating and combining uncertainties, fault tree analysis, and Bayesian inference may be used to systematize the estimates of vulnerability. However, repeated testing of systems, and subsystems, at as high a simulated threat level as possible, is essential with this approach. Whatever method is used, the uncertainty of the result should be clearly emphasized to decision makers lest oversimplification result.

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*A study by the Committee on Electromagnetic Pulse Environment, National Research Council, supported by the Defense Nuclear Agency.

PROBLEMS AND OPPORTUNITIES IN ELECTROMAGNETICS EDUCATION

Edmund K. Miller
The University of Kansas
Lawrence, KS 66045

As Bob MacIntosh of the University of Massassuchetts once observed in an AP-S Newsletter, it's easier to teach and learn 1's and 0's than Maxwell's Equations. That fact is one of the reasons why electromagnetics is not very high on the list of majors selected by EE students. The inevitable result of EM's disfavor is that fewer students are selecting EM courses as options or electromagnetics as a discipline. The situation is not helped by the fact that for someone to become truly productive in the field, either an MS degree with an EM specialty or several years of experience in electromagnetics are required. Something must be done to turn the situation around or the prospect must be faced that future national needs will not be able to be met.

The basic question of course is "what can be done?" The answer to this question might not only solve the problem but also provide an opportunity to develop a better foundation in EM both for students who select it and those who have been long-time EM practicioners. One way to do so is to recognize that today's students are picture and video oriented who might be "sold" more easily on EM if that fact were exploited. Electromagnetics suffers from being abstract and mathematically intensive, but today's computer graphics technology can go a long way towards rectifying this problem. Not only could computer graphics make learning EM more interesting and enjoyable, but it can also enhance the understanding of those with many years of involvement. These basic questions will be addressed in this presentation, as well as related issues such as where the EM teachers are coming from.

PC MOVIES ON THE MACINTOSH: AN INNOVATIVE WAY TO LEARN ABOUT FIELDS AND WAVES

Edmund Miller
Department of Electrical and Computer Engineering
The University of Kansas, Lawrence, KS 66045

As personal computers enter their third generation, the capabilites they provide have changed from being merely tantalizing to truly productive. The problems that can now be solved using PC's are significantly complex, and range from business-oriented spread sheets to engineering and scientific applications. Although there will always be problems not amenable to PC application, the variety that can be handled on a PC will grow as PC's become more powerful. A specific area where PC's are likely to become even more useful is that of providing a real-time experimental environment for enhancing education.

One such possibility is demonstrated in this presentation. Trhough its Faculty Author Development Program, Stanford University is stimulating the introduction of PC's into the classroom. A specific example is provided by a series of Macintosh programs being developed for use in undergraduate physics courses by Professor Blas Cabrera and a team of undergraduate student assistants. Disks are being produced for use in mechanics, modern physics and electricity and magnetism. The modules on each disk give the student a chance to conduct experiments and to see the results presented graphically in real time. By selecting experimental parameters and playback variables, the student is given a chance to explore various situations, to draw conclusions and to test them with subsequent experiments. Of particular interest are "movies" depicting the fields of an accelarated charge undergoing varous kinds of motion some of which will be deomonstrated in this presentation. As PC power grows, these kinds of applicatons in education are sure to expand and provide a truly stimulating educational environment.

GRAPHICAL METHODS FOR ELECTROMAGNETIC METHODS

Brian Cabral
Lawrence Livermore National Laboratory
P. O. Box 808, L-156
Livermore, CA 94550

Theoretical engineers and scientists, especially in EM areas, have increased their use of computer based modeling to solve more complex problems. As the problems grow more complex so does construction of the models and interpretation of the computed results. Computer based tools can be used to help the engineer build the model and interpret the results. Specifically computer graphics provides an ideal tool which can aid the engineer in visualizing both of these types of data. Furthermore the engineer must be able to interactively manipulate the displayed data; rotating, scaling, and picking data items at will. The visual representation and the high level of interactivity allow the engineer to verify the model and better interpret the results.

Success of an interactive display tool lies in the speed and quality of the graphics system. Computer graphics software and hardware technology has advanced to a level that will allow for high speed display and transformation of graphical data. During the last year research and development has been done to integrate a high performance graphics workstation into EM research. This research has focused on displaying both the modeling and the resultant data. Four prototypes were developed which allowed the engineer to transfer the data from the modeling computer (CRAY or VAX) to the workstation. The first was a display tool for verifying 3-D finite difference models. The second was a similar model verification tool for underground EM acoustical models. The third and fourth tools displayed 4-D (3 spatial and one color) resultant data. All these tools operated directly on the engineers data and were highly interactive.

The tools discussed here mark a departure from traditional computer graphics which were stationary or static. The engineer using static graphics must display one image at a time. This usually takes many minutes and requires textual input to the graphics software to change the image. With dynamic graphics the engineer uses a mouse or some other interactive device to change the image. Furthermore the image usually changes instantly or in the worst case seconds later. This increases the temporal density of information available to the engineer. In the case of finite 3-D model verification the scientist is aided by the ability to rotate the model and zoom in on suspicious model elements.

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 funded by The Defense Nuclear Agency, IACRO 86-837.

ENHANCING THE PERSONAL COMPUTER WITH A 32 BIT COPROCESSOR BOARD

Karen George
The BDM Corporation
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The IBM PC/XT/AT and clones present an attractive, cost effective alternative to centralized computing with a timesharing system such as the VAX 11/780 with VMS. For physics applications, particularly in EMP, the problems often require more memory and speed than the IBM PC/XT is capable of providing. Even with the PC/AT, speed is a serious shortcoming.

The addition of a 32 bit coprocessor board to an IBM PC/XT or clone offers a single user system potentially comparable to half a VAX 780 for a cost under $10,000. The Definicon Systems DSI-32 coprocessor board is designed around National Semiconductor's NS32032 full 32 bit CPU with a 32 bit databus, and occupies one full expansion slot. the NS32032 is supported by the NS32081 floating point accelerator and 2 Mbyte of RAM. Definicon supports three compilers, C, PASCAL, and FORTRAN, an assembler and associated software to interface the coprocessor board with the MS/PC DOS operating system. The large, fully addressable memory allows the development of larger, more complex codes than can be currently handled by the PC. The full language compilers potentially offers easy porting of large codes from a mainframe environment to the PC/DSI system.

BDM has recently purchased the DSI-32 coprocessor board. We have installed this board in an AT&T 6300 PC. This paper will cover our experiences with the DSI-32 coprocessor board. Specifically, ease of use, benchmarks, and problems will be discussed. A comparison of this system with the VAX and the PC without the DSI-32 will be presented.

ALTERNATIVES TO FORTRAN FOR USE ON
DESKTOP MICROCOMPUTERS

by

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The computer language which has been most often used for scientific work is FORTRAN. Most scientists have been trained to write FORTRAN, efficient compilers exist, and large program and subroutine libraries are readily available. Although originally written for use on large mainframes, FORTRAN is now available on many desktop microcomputers. FORTRAN is a relatively old computer language, however, designed long before the desktop microcomputer was available. It is thus useful to consider other programming languages which may have advantages for microcomputer use.

The purpose of this paper is to discuss such alternatives to FORTRAN for scientific computing on desktop microcomputers. The characteristics of newer microcomputer languages, such as Pascal, C, Modula2, Ada, Lisp, Logo, Smalltalk, and Forth will be briefly reviewed and compared. The bulk of the discussion, however, will center on the Forth computer language.

Forth is a relatively little known computer language with a number of unique characteristics. It was originally written for instrument control, although it has since been used for a variety of programming tasks and implemented for use on virtually every microcomputer. It has the advantages of requiring little memory, being interactive (incrementally compiled), running relatively fast, and being easily extensible. It has been used for several microcomputer projects at JAYCOR and found to be extremely versatile and powerful. It is our experience that complex codes can be created and debugged in relatively short times. Forth has also been criticized as being difficult to learn and very hard for anyone but the original programmer to read.

The paper will describe unique features of the Forth language and point out why it may be a good alternative to FORTRAN for scientific computing on microcomputers.

THE USE OF SPREADSHEETS AND OTHER COMMERCIAL MICROCOMPUTER PROGRAMS AS SCIENTIFIC AND ENGINEERING TOOLS

by

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There are several commercially available microcomputer programs aimed at making various types of calculations easier. Spreadsheets, such as Visicalc™, Lotus 123™, Multiplan™, and Excel™, are one category of such software. Although originally developed primarily for accounting and business planning purposes, the newer speadsheets are useful for all sorts of numerical manipulation and for preparing graphical displays. Another example of a productivity tool especially designed for use by scientists and engineers is the TK!Solver™, a program designed to help solve various types of equations.

This paper will discuss the use of such programs for certain scientific calculations. For example, the cells of a spreadsheet can be considered as representing spatial cells of a finite difference grid. One can thus use the iteration feature of such speadsheets to do such things as solve Laplace's equation in two dimensions and calculate 2-D capacitances. Similarly, the time-dependent response of simple transmission lines can be calculated and results automatically plotted with the newer more powerful spreadsheets.

Examples of such calculations will be given, along with a discussion of some of the limitations. One such limitation is the fact that spreadsheets are written to be quite general and thus are not optimized for specific problems (as can be done in writing a custom program). Calculations are thus not particularly speedy and complex numerical problems may easily exceed the capabilities of such tools.

The characteristics and possible uses of other specialized mathematical and scientific tools such as TK!Solver™ will also be discussed.

THE FAST FOURIER TRANSFORM (FFT)
AS IMPLEMENTED ON PERSONAL COMPUTERS

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Abstract

The fast Fourier transform (FFT) as originally described by Cooley and Tukey has long been used on mainframe computers for data processing applications. In the area of EMP analysis, FFTs are often used for constructing transient responses of calculated or measured CW data, and in analyzing pulse data taken in an EMP simulator. Furthermore, with the proliferation of personal computers, the use of FFTs in interactive data processing is becoming quite common.

Unfortunately, the use of an FFT is often not straightforward, due to the inherent limitations of the algorithm. The effects of aliasing often cause erroneous results to be generated and misinterpreted. Furthermore, the inverse FFT of an analytically derived spectrum can often lead to poor results.

Notwithstanding these difficulties, the FFT is a powerful tool if used properly. In this paper, a review of some of the pitfalls in the application of the FFT to transient analysis is presented, and hints as to the proper usage of the FFT on personal computers are given.

TOOLKIT

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The advent of fast microprocessors has made possible the development of extensive processing capability independent of the availability of a mainframe computer. TOOLKIT is a general purpose signal processing code developed at BDM to support the analysis of transient EMP responses using both analytical models and test data. The code includes a host of functions for operating on data such as:

- BOTH INTEGRAL AND FAST FOURIER TRANSFORMS
- PRONY POLE/RESIDUE EXPANSION
- ZERO PHASE DAMPED SINUSOID REPRESENTATION
- ANALYTIC WAVEFORM GENERATION
- LOW, HIGH, AND BANDPASS FILTERS
- INTERPOLATION
- INTEGRATION AND DIFFERENTIATION
- INTEGRAL AND FOURIER TRANSFORM BASED CONVOLUTION
- ADAPTIVE NOISE CANCELLATION
- DATA SMOOTHING IN TIME AND FREQUENCY DOMAINS
- GRAPHICS DISPLAY USING LINEAR AND LOGARITHMIC AXIS
- MULTIPLICATION, DIVISION, ADDITION, AND SUBTRACTION
- ASCII DATA STRUCURE TO SUPPORT EDITORS AND DATA TRANSFER
- DATA INTERPOLATION, TRUNCATION AND SCALING
- AUTOMATIC BACKUP DURING OPERATION
- SCREEN OR LINE PRINTER OUTPUT
- SELECTABLE DISK I/O

The code is menu driven and allows the user to define all operations and processing parameters. There are 3 primary menues available supporting the the general categories of data I/O, data analysis and data editing. The full capabilities of the code will be presented and a microprocessor made available for demonstration and general use.

EMP Hardening Topology Expert System (Hard Top)

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ABSTRACT

It is sometimes necessary to retroharden military systems to the effects of EMP. These systems, e.g., ships or aircraft, are generally quite complicated from an electronics viewpoint, perhaps having an electrical and electromagnetic topology which has evolved in a semi-random fashion over long periods of time. It is difficult to analyze the hardening and shielding levels of a system which has evolved in such a manner; it is even more difficult to design "fixes" which are compatible with the existing system, i.e., cause no undesirable side effects, cross couplings, interference, etc. Ideally, we would like to be able to identify all incomplete shielding topologies, ground loops, cable cross-coupling paths, and other EMP coupling points. We would like to be able to prescribe fixes in terms of additional (or better designed) shielding, appropriate protective devices (active or passive), cable re-routings, etc. Ideally, we would like to expose the entire system to threat level EMP environments in order to measure all important responses and confirm the effectiveness of the prescribed fixes. In lieu of full-scale environment exposure, it would be desirable to accurately analyze the system responses to several lower level tests, e.g., current injection or dipole radiation and extrapolate the resulting measurements to the responses which would have been obtained had a full-scale test been conducted.

The development of microcomputer and expert system technology has reached the point where it now appears possible to approach this ideal situation. Specifically, it should be possible to develop an expert system which can perform the desired analysis of a real system and which can even be run on one of the newly introduced lap top computers in real time at the site of the test. Such a real time system would provide the instant feedback which is so desirable in analyzing the effectiveness of a recent hardening fix. It is probably safe to say that the major factor hindering the development of such a system is not the hardware or software technology, but the development of an appropriate knowledge base which can be used by the expert system.

This note explores a possible architecture for such an expert system. It is determined that the best form for the topology knowledge base is one that mimics the topology data base: graphic. Rather than describing the knowledge base in the common form of "if-then" rules, which turns out to be very cumbersome and inefficient, the rules are described in terms of nodes and branches. Standard pattern matching techniques can then be used to connect rules and topology data. A specific graph model is explored as a candidate data base structure. Examples of the use of this data base are shown.

USING COMPUTER-AIDED DESIGN (CAD) TECHNIQUES TO ANALYZE HEMP COUPLING INTO AIRCRAFT

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Numerical coupling analyses are often used in support of EMP hardening programs. Such analyses provide input to EM Hardness Assurance/Maintenance efforts or simulation studies. One of the most powerful analysis techniques makes use of three-dimensional Maxwell solvers. Widespread use, however, has been limited by the time/cost of running such codes. This paper explores the interfacing of computer-aided-design (CAD) techniques with a three-dimensional finite-difference Maxwell solver to increase the efficiency of such analyses. To illustrate, the HEMP aperture penetration into an aircraft fuselage is studied.

CAD typically represents design as simple geometrical objects (boxes, cylinders, spheres, wedges, etc.) and concatenates these objects. The approach taken was to develop an interface code which will interpret these geometrical structures and project it onto a finite-difference grid. The numerical algorithm used will be discussed.

To illustrate the power of this technique, an example is presented. The HEMP penetration through the window of a hatch door is studied. The coupling to overhead cables is then calculated with details of the internal geometry included. Cable current both with and without window protection (screening) are presented.

A Mobile EMP Simulator (MEMPS)

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and

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The Swiss Confederation, with the support of EG&G, Inc., and Physics International Company, has developed a Mobile EMP Simulator (MEMPS) to be used for testing the EMP hardness of military and communications system.

The simulator consists of a hybrid antenna driven by a 4-MV biconic pulse generator. The antenna and generator are supported by a fiberglass reinforced plastic structure which can be disassembled readily for transport between test sites. When erected, the center of the pulse generator is 20 meters above the ground surface, and the two ends of the antenna are 60 meters apart. The design of the support structure allows test objects such as fighter aircraft to be placed directly below the pulse generator for maximum field strength testing as well as off to the side for "broadside" tests at various angles of incidence. The design also allows for rotation of the hybrid antenna within the structure. Future capabilities include variation of the pulse generator position within the antenna and driving of a vertically polarized antenna supported by the same structure. A continuous wave (CW) source also can be used to drive the antennas.

The MEMPS system includes a state-of-the-art data acquisition system employing fiber optics for data transmission, transient digitizers for data recording, and a powerful analyst software package allowing concurrent data processing.

The system became operational in late 1985.

Prediction of Frequency Spectra for a Hybrid Type Simulator Including the Effects of Reflection from a Layered Surface

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The frequency spectrum of an EMP pulse measured at a given point in the test volume of an EMP simulator of the hybrid type, including the effects of its reflection by the ground surface, can be predicted with a reasonable degree of accuracy given a knowledge of the electromagnetic parameters of the soil. Parameters which must be known are the dielectric constants and the conductivities for the different soil or rock layers. Water content is also a factor considered in the derivation of the expressions for the frequency spectra of signals resulting from a known pulser output waveform.

Analytic studies using a plane wave model were conducted to determine the influence of dielectric constant and of conductivity on the magnitude and phase of the reflected and transmitted electric fields. Additional studies examined several frequency dependent dielectric constant and conductivity models and their effects on reflected and transmitted fields. The effects of layering and of multiple reflections have also been examined.

Modeling of an ideal simulator was done with a pseudo point source employing plane waves passing through the pulser location. A double exponential waveform was assumed to be generated by the simulator. The results are compared to measured data taken with the Swiss Mobile EMP Simulator (MEMPS).

Radiated Fields From a Vertically Polarized Dipole Antenna Using an Improved Pulser/Antenna Model

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A vertically polarized dipole antenna is used as a wide-band radiator of special waveforms for EMP simulation. The antenna consists of a large right circular cone with its apex located on the ground. Special resistive loading is used in the antenna so that the current injected into it at the apex decreases linearly with height and becomes zero at the top, while maintaining a constant waveform.[1] This particular, special resitive loading results in an antenna equivalent circuit of the total antenna capicitance in a series with its characteristic impedance. The radiation fields are calculated from the antenna current, and the total fields are then calculated from the radiation field.[2] The input current to the antenna is derived from the equivalent circuit of an ideal pulse generator, including the output switch inductance and generator shunt resistance, which give the pulse rise time and late time decay, respectively.[3] The particular model discussed also includes a resistive load in parallel across the antenna input which can be varied to change the late time waveforms.

This work was sponsored in part by the U.S. Naval Sea Systems Command under Contract N00024-84-C-5357.

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EMPRESS II - A Program Overview

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EMPRESS II, the U.S. Navy's Electromagnetic Pulse Radiation Environment Simulator for Ships (II), will be a threat-level EMP simulator facility for the Navy's surface fleet. EMPRESS II is currently under development and is to become operational in November 1987. EG&G WASC, Inc. is the prime contractor to Naval Sea Systems Command (NAVSEA) for the simulator and data systems. Maxwell Laboratories, Inc. is under contract to the Defense Nuclear Agency for the 7-MV pulser.

EMPRESS II has operational requirements which exceed in many respects those of any existing EMP simulation facility. The principal objective of this presentation is to describe the major differences and to introduce the approaches being taken to achieve them. Several companion presentations will provide more detailed insights into those areas of development of potential interest to the EMP community.

This work was sponsored by the U.S. Naval Sea Systems Command under Contract N00024-84-C-5357.

RADIATION TEST FACILITIES AT HARRY DIAMOND LABORATORIES

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The U. S. Army's Harry Diamond Laboratories (HDL) have a unique combination of ionizing radiation testing facilities and services which can be configured to tailor tests to the individual testers' needs. This paper describes the capabilities of both the Aurora and High Intensity Flash X-ray (HIFX) facilities for prompt dose rate testing. The Cobalt-60 (Co-60) facility with its several sources and planned upgrades is useful for total gamma dose testing. HDL offers a test service called Aurora Conducted Test (ACT) which provides those testers who need a full range of testing but only a limited number of shots, the possibility of testing on a non-interference basis with our regularly scheduled tests. In addition, this paper will briefly describe our planned High Power Microwave (HPM) facility for tactical systems testing. This system will initially consist of a 200MW peak power pulser with 50ns pulsewidth operating at 8.4GHz. Future operating frequencies are planned from 3 to 12GHz.

Abstract

A Comparison of Free Field and Current Injection Induced Transient Surface Current Density Waveforms

by

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We have investigated the transient surface current density waveforms on metallic cylinders and a scale model aircraft. This paper compares concepts of free field and current injection induced waveform equivalence based on several criteria: total energy, frequency (spectral) content, peak amplitude, and rate of rise/fall. Data from a scale model test program is used as a baseline. The study considers the criteria for comparing waveforms from two origins. One waveform comes from best estimates of free field electromagnetic coupling onto extended C^3I system conductors. The other waveform is bounded by the state-of-the-art and practical limitations in full-scale current injection electromagnetic testing. Test fidelity criteria are derived based on the equivalence of the two waveforms.

A Low Cost Damped Sinewave Generator

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A low cost damped sinewave generator (DSG) has been designed, built, and tested. The frequency range is from 10kHz to 100MHz. The heart of the DSG is an MC1596 Balanced Modulator - Demodulator. The carrier input signal is from a standard signal generator and the modulating signal is the decay voltage from an RC network. The voltage decay (circuit Q) is readily controlled by the selection of the resistor-capacitor networks. The damped sinewave generator was built to provide a Q of 24 at eight frequencies: 10k, 100k, 500k, 1M, 5M, 10M, 50M, and 100MHz. The operator sets the carrier frequency and selects the appropriate capacitor from the eight available. The "peak" output voltage is 0.5V at 50 ohms. This signal can be used to drive a high power wideband laboratory amplifier to simulate the EMP damped sinewave requirements.

Performance of Linear Amplifier Systems in Direct-Drive Applications

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Damage and upset assessment of individual systems and subsystems by means of direct injection has proven to be a cost-effective and practical supplement to full system illumination. Capacitive energy storage type pulsers were originally used for the signal source due largely to their availability from other testing programs. However, increased application of direct-drive testing has resulted in a demand for more versatility in the driving source. Of particular concern is the requirement to drive at very specific frequencies at which individual pins show vulnerability. Cost and logistics place severe limitations on the number of individual frequencies that may be practically supported using energy dump sources. Linear amplifiers may be used to drive at essentially any frequency or combination of frequencies within the limitations of the unit assuming the waveform in question can be generated at some low level. However, linear amplifiers also have certain limitations that must be considered.

A comparison of linear amplifier pulsers to discharge type pulsers is reviewed. The advantages of these two approaches are discussed citing applications where each has advantage. Practical limitations of drive level versus size, input power, and portability are reviewed for the linear amplifier system. A detailed discussion of the actual performance parameters of typical linear amplifiers used in the direct pin drive application is presented. Distortion, impedance transformation, high power combining, and VSWR considerations are addressed. Actual performance data of a 2-kW RMS system is presented showing the trade off between maximum available drive and distortion, distortion minimization using push pull combining, and drive limitations for both direct and transformed output.

Performance of Large Current Drivers

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Vulnerability assessment of electronic systems to EMP and SGEMP by means of direct injection is an economical and relatively easily implemented test program. Bulk injection into the total cabling of various systems and subsystems is requiring increasingly larger geometry drivers to accommodate the physical size of the cabling.

As the geometry is increased, performance parameters are affected. The low frequency cut off is increased by the increased magnetic path length reducing the magnetizing inductance. The increased winding length of the excited winding lowers to useful, upper frequency limit determined by transmission line effects. The increased leakage reactance causes a high frequency break in response below the maximum usable frequency.

A 4-cm and a 10-cm ID driver were constructed and evaluated. Both were designed for an operational frequency range of 1 kHz to 100 MHz and a maximum power input of 4 kW RMS. The performance of these units as both drivers and sensing probes was investigated. Comparisons of drive response as a function of effective load impedance were recorded for loads ranging from a short circuit to 1000 ohms over the frequency range of 10 Hz to 200 MHz. The effect of the driver response characteristics in applications using damped sinusoids was demonstrated. Also, the effect of multiple drive windings was investigated.

ANALYTIC EXTENSION OF FREQUENCY DOMAIN THIN WIRE ANTENNA EMP CURRENTS TO A THREE DIMENSIONAL AIRCRAFT MODEL

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The internal response of an aircraft may be conveniently separated at the metallic pressure hull (skin) into internal and external interaction problems. The coupling between the problems is introduced as multiple local internal $\dot{M}$ or $\dot{P}$ dipole sources corresponding to TEM or aperture penetrations. Each $\dot{M}$ or $\dot{P}$ source is driven by the local external values of current density or charge density.

Frequency domain method of moments techniques were used to calculate the external response of an aircraft. The thin wire formalism employed in the calculation obscures the azimuthal current distribution. A normalized functional dependence of current density with azimuth was assumed. While this provided the desired current density, the validity of this approach was not known.

A check on the validity is provided by comparing data from aircraft test measurements of current density with those calculated from method of moments and azimuthal expansions. The available aircraft data, however, was obtained from simulator measurements. The simulator provide significantly non-uniform, non-planewave excitation and further, the aircraft was on a ground plane somewhat distorting the azimuthal current distribution.

To provide the best validation of the method of moments results, the azimuthal function was modified to account for the ground plane, an effective E field driver was extracted from the simulator field mapping and the resultant current density waveforms coupled to the measured current density. Both time domain and frequency domain amplitude comparisons are very good and waveform fidelity was excellent. With these favorable results, much more confidence could be placed in calculated airborne external skin responses.

NUMERICAL SOLUTION TO MAXWELL'S EQUATIONS WITH NON-ORTHOGONAL GRIDS*

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In 1966 the present author published a numerical scheme based on finite-differencing Maxwell's equations in rectangular cartesian coordinates (K. S. Yee, IEEE Trans. on Antenna and Propagation, Vol. AP-14, No. 3, P. 302-307, 1966). It has been used by many authors to compute complicated time-domain scattering problems. (D. E. Merewether, IEEE Trans. on E/M Compatibility, Vol. EMC-13, No. 2, p. 41-44; R. Holland, IEEE Trans. on Nuc. Sci., Vol. NS-24, No. 6, p. 2416-2421, 1977; A. Taflove and K. Umashanka, IEEE Trans. on E/M Compatibility, V. 24, No. 2, p. 173-203, 1982; K. K. Mei, A. Cangellaris, and D. J. Angelakos, Univ. Radio Sci., Vol. 19, No. 5, p. 1145-1147, 1984). Recently, the scheme has been generalized to non-orthogonal coordinates (R. Holland, IEEE Trans. of NS, Vol. NS-30, No. 6, p. 4589-91, 1983) and to a conformal mesh zoning with an interpolation through a quadratic polynominal (K. K. Mei, etc. Univ. Radio Sci., Vol. 19, No. 5, p. 1145-1147, 1984).

It is the purpose of this paper to propose a general scheme which does not require the zones to be bounded by orthogonal surfaces. The scheme does not require elaborate interpolation, thereby compromising its accuracy. However, the scheme is very flexible and easy to understand. It is specifically devised to do away with stair-casing in case of an irregular boundary. A specialization of the proposed scheme is also presented. It is useful for cylindrical geometry without any assumption on cylindrical symmetry of the electromagnetic fields.

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

THE USE OF TRANSMISSION-LINE MODELLING (TLM) IN EXTERNAL INTERACTION PROBLEMS

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Transmission-line modelling (TLM) is a time domain numerical technique which has been used for solving electromagnetic fields [1], diffusion and lumped networks. TLM models the propagation mechanism of EM waves by filling 3-D space with a network of intersecting transmission lines. This renders the problem discrete in both space and time since the exact solution is, in effect, a stable time stepping routine. The modelling process is simple, and efficient in the use of computer resources.

The fundamental theory of TLM, and the associated software techniques, have been developed over the past few years so as to enable it to be used for investigating a variety of electromagnetic hazards problems in the EMC, EMP and lightning areas [2],[3],[4]. This paper outlines the principles of TLM, including a brief comparison with other techniques, describes some of the recent developments, and discusses its validation on a series of problems for which solutions are known, either from theory or from experiment; it also discusses some work in the area of whole aircraft surface current injection techniques.

Specifically, we discuss the size of working volume required for a TLM solution, and its boundaries, the application of TLM to determining the surface currents on cylinders, for which considerable detailed results are available from other techniques and from experimental work, and its application in aperture penetration problems. We also discuss the associated graphics techniques that have been developed to make the input and output processing comprehensible. We then develop these ideas and, as an example, show how they can be synthesized into a tool for assessing the practicability of certain conductor arrangements for whole aircraft current injection experiments.

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[3] P B Johns and A Mallik: "Prediction of the shielding effect of carbon fibre composite material using TLM with diakoptics"; IERE EMC Conference, University of Surrey (UK), September 1984.
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DIRECT TIME-DOMAIN CALCULATION OF THE RADIATED FIELDS DUE TO CURRENT TRANSIENTS

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Most calculations of radiated fields from antenna-like structures are performed in the frequency domain; thus, the analysis of fields due to current transients usually requires the use of techniques such as the Fourier transform to get results in the time domain. In addition, many frequency-domain results are valid only in the far field region. The authors have developed a method for calculating both far and near fields directly in the time domain, thus eliminating the need for time-consuming transforms, and bypassing problems associated with these transforms (such as truncation error, aliasing, and so forth).

A brief outline of the new method follows. First, the transient current traveling waveform is expressed as a discrete time series, and then decomposed into a sum of ramp waveforms; each current ramp is zero until a given start-time, and increases linearly thereafter. Then, each ramp is allowed to propagate along a straight, lossless wire of arbitrary length. The expression for the magnetic vector potential for a single ramp is integrated exactly (i.e. without simplifying assumptions); the integration requires special care with respect to retarded times and spacial limits. Then, the magnetic and electric fields are obtained from the vector potential, and finally, the fields for all ramps are superposed. The method may be applied to real-world problems in the following manner : the current transients on an antenna structure (which may include both linear and non-linear loads) are calculated with a network analysis code; node currents are converted into traveling waves along the paths between nodes; each traveling wave is expressed as a sum of ramps; and finally, the fields from all ramps are superposed to yield the total fields.

This work is being performed in support of an analysis of electromagnetic interference caused by switching operations in high-voltage substations, and is sponsored by the Electrical Power Research Institute (EPRI), Palo Alto, California.

COUPLING OF A PLANE WAVE TO A SQUARE METAL PLATE

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A flat, square metal plate, one wavelength on a side, illuminated at normal incidence by a plane wave polarized parallel to an edge has been studied experimentally. Utilizing small electric dipoles and small loops with high impedance leads as sensors the distribution of the surface charge density and the surface current density components have been measured over both the front, directly illuminated, surface and the back, or dark, surface. These induced surface distributions constitute the coupling phenomena for the system. The results obtained for the quantities shall be presented in this report. The behaviour of these physical response quantities are of special interest near the plate edges.

Effects of thickness of the metal plate have been investigated. Results of measurement of the distributions of the induced surface charge density and the surface current density for plates 1/100 of a wavelength thick and 1/8 if a wavelength thick shall be shown and compared. Finally the measured surface current density at the center of the back face of the plate shall be shown as a function of plate thickness out to a thickness of just over a wavelength.

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Abstract

A Model to Predict the Electromagnetically Induced Currents on a Cylinder Plus Single Wire

by

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This paper describes the modifications made to an existing computerized electromagnetic coupling model. The modifications analytically changed the model from one that calculates the external skin currents induced by electromagnetic energy at the junctions between a stick model aircraft and its two attached trailing wire antennas (TWAs) to one that calculates skin currents at any location on a cylinder (stick approximation) with a single wire attached. A linear response is assumed. In addition, the modified model includes the effect of reflections from the wire termination. Two different methods of reducing and changing the equations of the model are described and the two results are cross-checked. These modifications were performed to improve the model and to validate and benchmark it by comparing its outputs with measurements made on a cylinder with an attached wire in an electromagnetic field. A sample graph of the model's output and, for comparison, a test measurement for the same conditions are included in this paper.

RESPONSES OF F-106B TO SIMULATED ELECTROMAGNETIC PULSE (EMP)

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In this paper, the external and internal responses of the F-106B aircraft to simulated EMP are presented and discussed. The responses were acquired from the flyby test at the Vertically Polarized Dipole (VPD) and inflight ground tests at the VPD and the Horizontally Polarized Dipole (HPD) at AFWL. Before the response data are presented, the data quality is examined in terms of signal-to-noise ratio, data repeatability, symmetry, and degree of agreement with analytical calculations and with extrapolated scale-model measurements.

The response data acquired for one test point from one type of simulation test of different aircraft orientations are first displayed. This kind of presentation is repeated for several test points and for all three types of simulation tests. In this way the effects of the orientations and polarizations of the incident waves on the responses can be seen, and the effects of aircraft interaction with the ground on the inflight-mode simulation can also be ferreted out.

The data are also displayed for a single pulser shot to show the sequence of interaction of the aircraft with simulated EMP. From the interaction sequence data, some ideas of the transfer functions that relate the external environments to the internal responses can be obtained.

MEASUREMENT METHODS OF EARTH SYSTEMS IMPEDANCE AT LIGHTNING AND EMP FREQUENCIES

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"CABLES DE LYON" company have settled measurement methods of earth system impedance versus frequency, covering a spectrum from 5 Hz to 100 Mhz. The three arrangements used are the following :

1) the first, including an impedance bridge, allows amplitude and phase impedance measurement of an earth system, from 5 Hz to 1.3 Mhz,

2) the second, using propagation of waves properties, leads to complex impedance determination, from 500 Khz to about 100 Mhz,

3) the third, at last, includes an impulse generator, which spectrum is comprised between 1 Khz and 2 Mhz ; so, it covers the frequencies domains of the arrangements 1) and 2), according to the previous results.

These methods have been experimented in the aim of comparing the frequency domain impedance values of following earth systems :

- earth rod
- connected earth rods
- earth conductor
- half-sphere
- vertical sheet
- horizontal sheet.

These experiments allowed us to determine each of the three methods application limits.

Measurement curves of impedance amplitude and phase of previous earth systems will be presented. Results analysis will allow us to define the better earth system configuration adapted to lightning and/or EMP discharge.

ELECTROMAGNETIC COUPLING TO CONDUCTORS WITH HELICAL GEOMETRY

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Abstract

In this paper the results of a calculation are presented that describe the coupling of electromagnetic radiation incident on an infinitely long conducting cylinder, partly shielded by a number of widely spaced, helically wrapped conducting wires which are embedded in a cylindrical dielectric jacket.

The coupling problem is formulated in the framework of transmission-line theory, wherein the cylinder and shielding wires are treated as elements in a multiconductor transmission-line system. Accordingly, the appropriate transmission-line equations for the cylinder and helices are solved, and the corresponding transmission-line parameters are derived.

A MODEL FOR PREDICTING THE SURFACE TRANSFER IMPEDANCE OF BRAIDED CABLE

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The objective of this effort was to develop a model for predicting the surface transfer impedance of braided cable shields. Such a model is very useful for developing specifications for EMP hardened aircraft that have reasonable life cycle survivability costs and for establishing base line values for hardness surveillance systems. The approach used to carry out this model development effort was to use theory to suggest the parameters that should be of interest and to use experimental data to determine the range and worst case values. Surface transfer impedance is the intrinsic electromagnetic parameter of a cable shield. Many studies have shown that it can be represented as the sum of a resistance, R, and a mutual inductance, M_{12}. To a first approximation, the resistance per unit length is determined by the amount of metal in the braid. Therefore the resistance is inversely proportional to both the shield thickness and diameter. The mutual inductance is due to both aperture and porpoising coupling, with porpoising dominant in most cables. The experimental data from a large number of cable samples measured in the BDM Laboratory shows that a worst case model for the resistance of a braided shield can be represented as $R = k/d$, where d is the cable diameter in inches. For single braid shields, $k = 4.5$ milliohms inches/meter. For double braid shields, $k = 2.6$ milliohm inches/meter. For large cables, (7/8 in.) the resistance of single braid is about 4 milliohms/meter and double braid is about 2 milliohms/meter. While theory suggests that the mutual inductance should be inversely proportional to the diameter squared, experimental measurements vary over two orders of magnitude. This is the result of various optimizations of the braid. The system should be designed for the worst mutual inductance if it is to be insensitive to small changes in the shield. Thus, the worst case model for mutual inductance is independent of diameter. The worst case mutual inductance is 3×10^{-9} H/m for single braids and 3×10^{-10} H/m for double braids. Note that cables have a very limited range of diameters; shielded pairs being within a factor of 2 of 3/16 in. and large cables are within a factor of 2 of 7/8 in. Thus, the resistance should not change drastically from cable to cable.

A model for predicting the surface transfer impedance of non-optimized braided cables has been developed. This model is based on theory and extensive measurements.

The resistance is inversely proportional to cable diameter. The mutual inductance is best modeled as being independent of diameter. The worst case cable overbraid model accounts for multiple layers of braid. This model could be refined to meet special requirements.

HOW BIG A HOLE IS ALLOWABLE IN A SHIELD - THEORY AND EXPERIMENT

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A question is frequently asked about the amount of damage that can be sustained in an electromagnetic shielding system before it is seriously degraded. The objective of this effort was to determine how big a hole can be tolerated in a cable or an enclosure shield without significantly degrading the shield. The approach that was used in this study was to use experimental data to determine the range of values expected from real hardware, use theory to understand the coupling mechanisms, apply an appropriate safety margin and use engineering judgement to determine the maximum hole size. Except for cases where the cable shield is almost completely severed, the resistance of a cable shield, and therefore its performance below a MHz, is insensitive to shield damage. The major effect of cable shield damage is to increase the mutual inductance component of the cable's surface transfer impedance. The mutual inductance is proportional to the magnetic polarizability of the hole, which in turn is proportional to the third power of the diameter. This theory is validated by many measurements. This theory has been applied to a typical cable shield (a .7 inch diameter single braid). Assuming that the transfer impedance of the hole is equal to the transfer impedance of 1/3 meter of cable and assuming that the mutual inductance of the braid is 30 pH/m, one obtains a mutual inductance of 10 pH for the hole. This corresponds to a magnetic polarizability of 24.8×10^{-9} m^3. The diameter of the hole must be less than 0.2 inches, which is rather large. For electromagnetically tight enclosures, the magnetic field attenuation is usually dominated by joint impedance. For enclosures with apertures it is inversely proportional to the magnetic polarizability of an aperture in the wall and proportional to the cross sectional area of the enclosure. Experimental measurements show that a 24" x 24" x 8" equipment box with a 50 dB surface magnetic field attenuation requirement could have a 3 to 4 inch diameter hole in it's wall or one face could be covered with 1/8 inch wire mesh and still meet the shielding requirement.

Degradation of a shielding system due to apertures can be calculated. The effectiveness of the shield is sensitive to hole size because it is inversely proportional to the third power of the hole dimensions. However, surprisingly large holes can be tolerated if the shielding requirements are modest (50 dB). This theory shows that small cables and enclosures are more susceptible to aperture degradation than large ones.

TRANSFER IMPEDANCE MEASUREMENTS ON AIRCRAFT CABLES WITH DEGRADED SHIELDS

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The effect on shielding performance of various degradations in cable shields is demonstrated with transfer impedance data taken on a range of cable samples. The types of degradations discussed range from drill holes in braided shields to loose and aged connector assemblies. Measurements taken on hardened cables from several modern aircraft are used to emphasize common problems with cables and demonstrate the need for hardness surveillance testing. Conclusions regarding the relative importance of the various degradation mechanisms to operational systems can be drawn from the data. In addition, areas are identified in which the current theory provides a poor estimate of the effect of some degradations.

EFFECT OF REMOVING SPRING FINGERS AND THE WAVY WASHER ON THE MEASURED TRANSFER IMPEDANCE OF A MIL-C-38999 SERIES IV CONNECTOR

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The surface transfer impedance of a MIL-C-38999-500 (Series IV) connector was measured in the intact condition, with varying numbers of the spring fingers covered with kapton tape and with the wavy washer removed. Voltage response was measured from 1 kHz to 1 GHz. Transfer impedance could be calculated up to 200 MHz. These measurements showed that: 1. The transfer impedance did not change significantly when up to 8 spring fingers were covered with tape. 2. The transfer impedance of the connector with all spring fingers taped was less than that of 1 meter of single overbraid. 3. The wavy washer was almost as effective as the spring fingers for insuring good contact between the plug and the receptacle.

INCREASED SHIELDING FROM TWO LAYERS OF CABLE SHIELDS IS GREATER THAN THE SUM OF THE PARTS

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A cable bundle overbraid can do more than increase the optical coverage; properly fabricated, two layers of shielding introduces an additional decoupling factor. A Green's function transmission line formulation is used to determine an expression for the combined transfer impedance through two layers of shielding that are separated by a dielectric but shorted at the ends. The inductive impedance of the transmission line between the two shielding layers is found to limit the current that can be induced on the inner shield. More than 40 dB of shielding enhancement at 3 MHz is predicted for a reasonable cable bundle overbraid configuration.

PRACTICAL CONSIDERATIONS FOR USE OF MULTI-ELEMENT NONLINEAR TERMINAL PROTECTION DEVICES

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The accepted/recommended techniques for power line overvoltage protection are reviewed*. A series of experiments to test the assumptions inherent in the recommended techniques are developed and described. The results of these experiments and revised recommendations are presented.

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*MIL-HDBK-419, Military Handbook, "Grounding, Bonding, and Shielding for Electonic Equipments and Facilities", Volume 2 of 2, Applications, Department of Defense, Washington, D.C. (21 January 1982)

ZINC OXIDE VARISTOR DEVELOPMENT

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Development of zinc oxide (ZnO) varistors for aircraft EMP protection has been a cooperative effort between the Navy and the AFWL. The objective was to develop varistor technology and obtain flight qualification experience on varistors in actual flight environments. Wing wiring varistors were selected for further development as difficulties had been experienced with the original units. Development of a new ZnO varistor unit was begun by AFWL with G.E. providing both the varistor element and packaging. Testing was performed by an independent laboratory (Wyle). A prototype design of 25 units was fabricated and tested. The design was refined and 150 additional units were fabricated. Of these, 25 were type approval tested, and 125 were acceptance tested and used for aircraft operational testing. Of the 125 units available, 72 were installed in 1984, and the remainder were held as a test control group and spares.

Tests were made of the stand-by power and to characterize the voltage/current curves of the varistors at the time of installation in Aug 1984, and subsequent tests were performed in Oct 1984, Mar 1985, and Nov 1985. From the raw E/I data set a best fit curve was determined for each varistor test. The fitted curve was then used to determine the slope of the voltage clamping plateau (the inverse of which gives a parameter, "a"), a measure of the voltage (Vnom) at exactly 3.0 ma current through the varistor, and a leakage current factor (Io) related to the leakage resistance of the varistor. These results, in addition to the stand-by parasitic power loss of the varistor at 120 V 400 Hz, were tabulated and analyzed for evidences of generic problems and to predict trends in the values of the varistor parameters.

The present preliminary judgement on the units is that, aside from high energy pulses, exhaust fumes and the heat environment are the worst enemies of the present units, and that future units should, where ever possible, should be hermetically sealed. It is also believed that seasoning or "burning in" of the varistor should prove valuable in screening out early failures and of stabilizing the parameters of the varistors prior to use.

METAL OXIDE VARISTOR BURN-IN

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ABSTRACT

Varistor degradation from unipolar transient pulsing is described. A varistor is a two port, non-linear, terminal protection device. In its non-conducting mode the varistor acts as an open circuit with a small standby current. In its conducting mode the voltage is clamped and large currents are shunted to ground. Degradation of the varistor over its lifetime was known to be a function of the cumulative energy of the transients shunted. An additional burn-in degradation has been identified. MOV's subjected to a single high energy transient display an increase in standby current and a decrease in clamping voltage. The initial burn-in may lower the clamping voltage by ten percent. Degradation from subsequent pulsing is much less pronounced. Also, the amount of degradation measured is dependent on the polarity of the measurement relative to the polarity of the pulse. After one pulse, the clamping voltage is lower when measured at the port opposite to the pulsed port than when measured at the same port which was pulsed. However, burn-in was evident for either polarity. Polarization of the permanent electric dipoles in the insulating matrix and the filling of traps at the metal oxide grain boundaries are discussed as possible mechanisms for the degradation.

IN-SITU CHARACTERIZATION OF LINEAR AND NON-LINEAR TERMINAL PROTECTION DEVICES USING TIME AND FREQUENCY DOMAIN TECHNIQUES

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ABSTRACT

Systems hardened against EMP often use terminal protection devices (TPD's) to insure that the LRU connector is strong enough electrically to be able to withstand the EMP induced transients. Since these TPD's may fail in ways that do not degrade normal system operation, they must be tested or characterized periodically. Two techniques have been developed and demonstrated for characterizing TPD's in-situ, that is, without disassembling the LRU. One is a time domain and the other is a frequency domain technique. Both can characterize linear as well as non-linear TPD's.

The time domain technique is essentially a high voltage time domain reflectometer that uses a short variable amplitude pulse as a probe signal. The pulse is short enough (a few tens of nanoseconds) so that it cannot damage the circuit even if the TPD is non-operative. The integrity of the TPD is determined by using pulses whose amplitudes are below and above a specified firing threshold and comparing the reflected pulses. The validity of this technique was demonstrated using standard laboratory test equipment consisting of an oscilloscope and a fast rise time transmission line pulser capable of producing a few tens of volts. This technique is able to easily detect proper operation of a non-linear TPD even when the TPD is isolated by meters of cable. The same technique can be used to detect the presence of filters installed at the end of a cable.

The frequency domain technique uses a computer controlled impedance analyzer in conjunction with a voltage source to map a three dimensional surface (impedance x frequency x bias voltage) that is characteristic of the particular TPD. The same equipment can be used to characterize linear as well as non-linear terminal protection devices.

The Connector Pin Varistor

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Abstract

A new tubular form of transient suppressor has been developed. Based on metal oxide varistor technology, the new connector pin varistor allows incorporation of transient protection directly into currently available connector designs. These new devices have suitable electrical characteristics for suppression of pulses resulting from EMP, NEMP, ESD and lighting. Electrical characteristics for these devices have been shown to be directly comparable to commercial disk varistors of comparable voltage and active volume. Physical construction of the tubes contributes to a relatively large conduction area and heat absorbing mass, resulting in the varistors ability to withstand relatively high transient peak currents and energys. Metal oxide varistor material of the same composition as incorporated in the connector pin varistor devices has been shown to be virtually impervious to electron and neutron irradiation of up to 10^8 rads and 10^{15} n/cm^2 respectively.

Development of the connector pin varistor was carried out at the Transient Suppression Products Operation of General Electrics Power Electronic Semiconductor Department under sponsorship of the Air Force Weapons Lab. The devices have been targeted for use in providing transient protection in both Aerospace and ground electronic systems.

THE DEVELOPMENT OF M.A.C.E. - A MICROCOMPUTER ASSISTED EMP COUPLING ESTIMATOR

by

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JAYCOR has recently developed the M.A.C.E. microcomputer program as a commercial product designed to assist the scientist or engineer in making rapid estimates of EMP fields and the resulting coupled currents and voltages. The M.A.C.E. program takes the form of an electronic handbook where engineering formulas are automatically calculated and response curves plotted for specific cases of interest. Furthermore, the various steps in the coupling process are automatically linked. Results are presented graphically and various types of plots can be generated.

The M.A.C.E. program is an experiment in trying to develop a tool which is both useful and educational. The intended user is the system designer or engineer who needs quick estimates of EMP response. The goal was to develop a computer code which is very easy to use and requires a minimum of experience with microcomputer details to operate. Versions have been written for both the IBM-PC/XT and the Apple Macintosh/Lisa.

This paper will review the problems associated with the development of such a computer code. Such problems include not just deciding what models to use to describe various parts of the EMP coupling process, but also deciding how to interconnect the various models and how to simplify the process so that results appear rapidly (i.e. how to make the code interactive). Problems in developing a simple user interface will also be discussed.

In particular, the differences and similarities of the IBM-PC and Apple Macintosh versions will be discussed. The Macintosh user interface (e.g. mouse, icons, and pictorial displays) was found to be quite effective in making the program easy to use and understand. However, the lack of a hardware floating point processor limits the 'number crunching' capability of this machine. The IBM-PC equipped with a 8087 numeric coprocessor, is significantly more powerful for detailed calculations, but generally has a less effective graphics display, making it more difficult to prepare a simple user interface.

Finally, potential enhancements to M.A.C.E. in particular and the electronic handbook concept in general will be discussed.

TITLE: Guidelines for the Use of a Micro-Computer for Modeling and Data Analysis

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ABSTRACT: Traditonally those of use writing software to model electromagnetic effects and those of us analyzing data from tests have employed main-frame and mini-computers in a time-sharing environment. Recently there has been a re-thinking of this approach, and a trend toward smaller more analytical formulations of our problems and concurrently the use of smaller personal machines to solve them.

At BDM we have developed a package of modeling and analysis codes to run on an IBM PC. Currently the package includes:

A two-dimensional Maxwell's equation solver,

An AC circuit analysis code,

A Method of Moments antenna analysis program,

An interactive stick model EMP analysis program to find resonant frequencies of an aircraft,

An interactive data analysis program which allows the user to plot, edit, and perform frequency and time domain analyses on both real and analytically generated data.

An interactive cable SGEMP model for determining pin responses.

This talk will provide general guidelines and details relevant to this sort of modeling, such as timings, accuracy, coding considerations, etc. Specific advantages (and disadvantages) to this approach will also be discussed. All of this will be presented in a framework relevant to the EMP analysis codes mentioned above.

TITLE: EMP Coupling Calculations Using Micro-Computer

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ABSTRACT: Accessible and readily obtainable estimates of EMP coupling are required for a variety of applications. This paper describes a model implemented on an IBM PC class microcomputer. The model is based on the solution of coupled transmission lines with distributed sources corresponding to the drive fields.

Conceptually, the model consists of characterizing a complex system by piecewise uniform sections of transmission lines. For instance, an aircraft could be characterized by 8-20 connected sections. The solution is based on an admittance matrix formulation. The currents entering a node between sections are related to the voltages at these nodes by the transmission line admittances, (frequency dependent terms that can include losses). Admittances associated with lumped loads can also be included. The source vector is a function of the driving electric field tangent to the section. Solving this matrix equation yields the node voltages. The voltage or current anywhere on the structure is expressed in terms of these voltages and the source.

The code has been written in a modular format which allows for easy changes to the geometry of the aircraft, the position of the aircraft relative to the ground, and the nature of the source. In fact we have used code to model two different airplanes and a helicopter. We have used it to model both plane wave electric field excitation and lightning (the later required changes in the computation of the admittance and the source vector).

Results for plane wave excitation of the F-111 will be presented and compared to similar calculations made on a mainframe as described by Holland (IEEE Trans. Nuc. Sci., NS-24, pp. 2416-2421, December 1977). This comparison shows that approximate engineering quality answers can be obtained with a small effort when compared to more rigorous models or test results.

CORONA MODELING ON A PERSONAL COMPUTER

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ABSTRACT

A numerical model for positive and negative corona discharges, suitable for use on personal computers, is discussed. Steady state results are compared with previous experimental work by Takahasi et. al. and theoretical work by Sarma and Janishewskyj. Time-dependent models are seen to be necessary for simulating negative corona, in general; Sarma and Janishewskyj appear to have achieved a steady state simulation through the use of an unphysically small Townsend gamma coefficient. The role of photoionization is discussed. Improved numerical techniques employing block-implicit methods and stiff solvers are also discussed.

The SGEMP Interactive Model: System-Level Cable SGEMP Analysis on a Microcomputer

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The SGEMP Interactive Model (SIM) is a simple but powerful computational tool for estimating the System Generated Electromagnetic Pulse (SGEMP) response of shielded cable to intense x-ray pulses. The development of SIM arose from the desire to provide design engineers with the means to interactively assess the intrinsic and relative vulnerabilities of various cable layout design options to a variety of possible nuclear environments very early in the design phase.

The SIM microcomputer code allows a designer to define any three-dimensional cable path among arbitrarily placed three-dimensional geometrical "primitives" that define the masses of user-defined materials composing the system. A one-dimensional photon transport model is used to calculate the x-ray fluence arriving at each incremental length of cable from the postulated external x-ray illumination. The external x-ray environment is defined in spectrum, direction of incidence, and pulse width by the user. The cable current response per unit length to the appropriately attenuated x-ray spectrum at each cable length increment is determined by the Low Fluence Residual Gap cable model. A lossy transmission line model integrates the time phased incremental current sources excited along the cable length to yield the time history of the open circuit voltage which develops at the cable ends.

The paper will describe the physics models incorporated, outline some of the options and capabilities of the code, and show typical results from a sample problem.

* This work performed under auspices of the Martin Marietta Corporation under subcontract no. GH4-112530.

Microcomputer Aided Circuit Analysis - The Pros and Cons

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With the availability of the microcomputer in todays' office place, more of the tasks formerly assigned to mainframes and minicomputers are now being handled by their smaller counterparts. Circuit analysis is no exception to this rule. BDM is just finishing a large aircraft communications system, using microcomputers for the analysis of all of its electronics. Both frequency and time domain analysis codes have been utilized. This paper will expound BDM's experiences and answer questions regarding problem setup and run-time increases versus computer accessibility. Bench mark trials from PSPICE and ECA will be presented. Further, the ability to transfer information directly to a data base for further processing will be discussed. There are many advantages and disadvantages to the use of microcomputers. There are also ways to enhance throughput with the microcomputer. With the pros and cons firmly in hand, engineers may find the micros a very useful analysis tool.

APPLICATION OF A PERSONAL COMPUTER IN PERFORMING TIME DOMAIN ANALYSIS

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The use of a personal computer in performing time domain analysis provides an efficient approach for determining design margins of semiconductor devices in response to EMP. The utilization of a time domain network analysis code provides a more realistic treatment of nonlinear devices while also providing circuit responses to arbitrary input waveforms. The capability also exists to analyze more than one semiconductor device at a time. The initial step in this process is to model the circuit path from the antenna through the first few stages of the electronics in order to identify the semiconductor devices that are most susceptible to an EMP threat. Diode and transistor model parameters are obtained from manufacturer's data sheets. The semiconductor models used preserve the device nonlinear behavior. The circuit description and model parameter data are entered into a file on a diskette. The analysis code is then called up to run the circuit file with a specified input waveform. Probe points are identified to be, for example, voltage and power across diodes and transistor junctions or a 50 Ω impedance representing a receiver input. In performing a time domain analysis, time step size is critical in order to obtain accurate results. The time step needs to be sufficiently small in relationship to circuit time constants while also being large enough to preclude excessive program running time. The analysis results are then written to an output file that can be called up in using a plot utility program for presenting analysis data in a graphical format. Graphs are generated representing the instantaneous as well as the average voltage and power versus time for all of the probe points identified in the analysis. In order to determine design margins for the semiconductor devices, the device average power is compared to a failure power model for that device. The failure power model represents a lower bound on device failure power as a function of time. The plot utility program can superimpose the failure power curve on the graph for average power for a particular device. The difference between the two curves is then the design margin for that device. Hard copies of the graphs produced can be obtained for inclusion into a written report or as part of detailed analysis for a major system.

In-situ TACAMO Filter Testing Using Drive Point Impedance Measurements

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The method of measuring the drive point impedance to test linear filters is the foundation for testing filters on the EMP hardened TACAMO aircraft. The test set is a portable test set designed to be used on the flight line for Hardness Maintenance support of the fleet. The drive point impedance measurement method is a single-ended test which can be performed with the EMP hardened equipment installed on the aircraft. The test set, consisting of a single equipment bay, is computer automated which dramatically increases the speed of the test and the accuracy of the measurements. Additionally, the test measurements are interpreted and a simple PASS/FAIL message is displayed for the test technician. The test set detects failed filters by monitoring the complex impedance of the linear filter elements. The complex impedance is analyzed to detect degradations in filter elements to identify areas of potential vulnerabilities. The test equipment includes a computer controller, a vector impedance analyzer, a switching matrix, a digital voltmeter, and a D.C. power supply (for testing voltage limiters).

Automated Switching for Direct Pin Drive Testing

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Automated direct-drive testing of all pins of various elements of electronic systems is becoming an increasingly popular method for operational upset and damage threshold verification. Practical application of this type of testing requires the use of a highly automated switching system.

This type of switching system must be highly reliable, accurately calibratable, easily configurable to essentially any connector, and in general of small geometry. The sensing of the potential and current drive signals must accurately represent the actual values at the pin under test, and the signal isolation to pins not under test must be high. Various approaches to the switching problem are discussed including coaxial relays, conventional miniature relays, reed relay elements, and industrial robots. The development and performance of a high performance switching system capable of driving in excess of 200 pins is discussed. Practical limitations to the number of pins that may be accessed in a single switch unit are addressed. Potential and current drive limitations are presented. Single-ended drive and differential drive, both balanced and floating with respect to ground, are discussed. The requirements of both passive damage tolerance testing and active upset testing are addressed.

EMP PIN INJECTION STRESS TESTING IN A PRODUCTION ENVIRONMENT

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Subsystem suppliers of electronic military products may often be required to demonstrate hardness to electromagnetic pulse (EMP) threats for each and every unit produced. A verification test to prove that specification requirements have been achieved can be accompolished by the application of damped sinusoidal transient pulses to the interface pins of a line replaceable unit (LRU). However, in a typical production acceptance test, a single LRU may contain several hundred pins, each of which must receive multiple injection pulses. Even for a moderate production rate, the volume of testing imposed by these requirements demands an in-house, dedicated automatic tester in order to maintain schedules. This presentation describes an instrument designed as a computer-controlled system capable of delivering a lengthly sequence of varying high voltage transient pulses to the interface pins at a rate of one pulse per second.

The pin injection system can automatically deliver the required transient to each pin, monitor the delivered pulse, record the test conditions, and archive the test results. It will deliver damped sinusoidal transients from 10 kHz to 100 MHz. The system containss a 100 ohm Thevenin source with an open circuit voltage controllable between 10 and 1500 volts. The system includes voltage and current sensing capabilities for monitoring delivered transients to within +/-3% It has a modular design to facilitate flexibility and adaptability. It can rapidly be reconfigured to change test frequencies, test levels, or accommodate a different LRU.

During execution of the test sequence, the microprocessor commands and coordinates the signal generator, the amplifier, the sensors and the data recording functions. The signal generator consists of an IEEE 488 bus-controlled waveform generator and modulator which produces a low-level transient with the desired wave shape. The amplifier is a gated pulse power linear amplifier which receives the low-level transient from the signal generator and boosts the signal to a high-level transient which is delivered to the pin under test through a highly reliable switching network. Voltage and current probes are built into the delivery end of this network so that the transient peaks are measured right at the pin. Data for each pulse is collected by these probes and is stored for inclusion in the test summary report.

The pin tester utilizes specific software to achieve customized control of the test sequence and specific connection hardware for each electronic system to be tested. Menu entries to the control console direct all test activities. Operator commands are self explanatory with each command prompt aiding the operator to select correct responses. Help functions provide detailed information when required. The menu structure guides the operator through proper test execution and increases the reliability of the test procedure by checking for correct conditions at each step. The system verifies EMP stress assurance requirements by automatically recording the test data, test configuration, test unit identification, operator identification, and calibration information. Test sequences are programmed to include self test and calibration procedures.

Shielding, Wiring, & Grounding for Optimum EMI & EMP Protection

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ABSTRACT

Shielding, wiring, and grounding practices are often in conflict with one another in the control of EMI and in EMP protection. Shields, grounds, and returns are often confused with one another, semantically. Shielding, by itself, cannot solve all problems, particularily in aerospace systems. A balanced approach is necessary, whereby shields, grounds, and returns are physically separate and play different roles. EMI and EMP protection of susceptible circuitry must become an integral part of the shield and ground system.

Systems with single-point and multiple-point grounds are addressed. Shielding, grounding, and filtering of noise emitters and susceptible receivers is treated as part of the overall scheme. A set of EMI/EMP ground rules and a checklist are provided for use by designers in circuit design and PCB layout. Good chassis ground on modern PCBs is difficult to obtain; alternative approaches are discussed.

I/O design for MIL-STD-461 and EMP is treated for both grounding schemes with trade-offs and alternatives for the suppression of EMI and EMP.

Cable Shielding
vs.
I/O EMP Hardening,
a
Trade-Study

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ABSTRACT

Off-the-shelf cable shielding on present-day DOD systems is limited to about 80dB shielding attenuation per meter length, at best, or about 10 milliohms transfer impedance at the lower frequencies. Most contracts require only 40dB minimum shielding attenuation for all cables. The trade-off between cable shielding and I/O hardening becomes severe when threat-level cable shield currents reach 600 amperes, peak, as on USN ships and USAF aircraft. This trade-study shows how the I/O hardening must be tailored to the cable shielding performance.

Work supported under USN Contract No. N00039-82-C-0146 and Raytheon.

"Robust" EMP Hardening of EIA Standard I/O Circuits and Constraints on Data Rates & Line Lengths

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ABSTRACT

Most DOD contracts contain nuclear EMP hardening requirements of black-box I/O circuits, many of which are digital TTL circuits whose interconnections are standardized in Electronic Industries Association (EIA) Standards RS-422, 232C, and 423 and the military equivalent, MIL-STD-188-114. The data rates between the interfaces are constrained by the length of the transmission lines between them, whose impedance and admittance continuously degrade the data waveforms as they propogate along the lines. "Robust" EMP hardening of the I/O circuits requires, at a minimum, filtering, current-limiting, and/or voltage-limiting, which further degrades the data waveforms. This paper addresses the minimum essential "robust" EMP hardening and the constraints that places on the EIA standard data rates and line lengths.

Work supported under USAF Contract Nos F19628-83-C-0101 and F19628-85-C-0004.

An EMP Upset Verification Test Methodology

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ABSTRACT

Conducted transient or EMP-induced upset of digital and hybrid subsystems can occur only if the subsystem's EMP transient protection allows transients to affect subsystem performance. Under these conditions, one may conclude that the subsystem transient protection is inadequate.

At the same time, one may also conclude that this protection is adequate, considering the complexity of modern avionics subsystems. Since digital subsystems change internal EM topology at a rate equal to the subsystems clock rate, and since the number of possible topologies (or states) is $\geq$ the number of memory states available to the subsystem, the probability that a single-event transient may degrade subsystem performance does, indeed, seem miniscule.

This paper presents a two step upset verification test methodology which addresses both viewpoints presented above.

In step 1, a test is performed to determine whether EM transients can affect subsystem performance. In this test, subsystem observability is maximized and success is defined in terms of accuracy of all subsystem outputs under transient excitation conclusions.

If all subsystem outputs are accurate under transient excitation conditions the subsystem is considered to be "hard" to EMP upset. Efforts are currently underway to evaluate the fidelity (realism) and testability (coverage) of such a test.

If the first test shows that EM transients have the capability to alter subsystem performance, a second test is proposed which quantifies the mission impact of the EM transients. In this test, critical system attributes are replicated, rather than simulated, and a number of realistic missions are completed. Success is defined in terms of required operational measures of effectiveness, such as delivered weapons CEP. An ICBM example is presented to illustrate the concept. Efforts are currently underway to generalize the approach for man-in-the-loop systems. If this effort is successful, the need for the first test may be eliminated.

Title: Upset Testing Methodology for Electronic Systems Which Utilize the MIL-STD-1553B Data Bus

Authors: Daniel M. Ritt, Jeffrey M. Brooke, William Prather, Gerold Rimbert

Affiliation: Messers Ritt and Brooke are with Mission Research Corporation in Colorado Springs, CO. Messers Prather and Rimbert are with the NTAAT Division of the Air Force Weapons Laboratory in Albuquerque, NM

Support: This work is supported by U.S. Air Force Contract DC-SC-4088-4

Abstract:

The MIL-STD-1553B "Aircraft Internal Time-Division Command/Response Multiplex Data Bus" is in widespread use in modern digital avionics subsystems. There has been a great increase in interest, in the past few years, in hardening and hardness assurance of digital systems subject to EMP and lightning. Recent efforts have moved from protection from burnout to protection and recovery from upsets. Methods are described for collection of MIL-STD-1553B bus traffic through the utilization of specialized hardware. Additional methods are described for computerized analysis of bus traffic to detect possible upsets. The hardware and software that is presented is currently being utilized in the upset testing of an inertial navigation subsystem. Finally, methods are proposed to enhance future testing.

EMP RESPONSE OF OVERHEAD TRANSMISSION LINES

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Abstract

This paper presents a time domain, integrated transmission line model which explicitly represents frequency dependent effects of line parameters, line grounding effects and EM coupling. The model involves three components; a) the model of the overhead conductors and the earth return, b) the model of the transmission tower grounding system and c) the EMP coupling model to the overhead conductors and transmission towers.

The model has been interfaced with the PSTS [1] program which is an offspring of the EMTP. The PSTS includes other power system network device equivalents, i.e. surge arrestors, transformers, etc. which are combined to form a network representation of an interconnected power system. The network solution yields the voltages and currents anywhere in the network, including the ground system. After the voltages are known, the voltage stress on tower insulators, circuit breakers and transformer insulation can be calculated.

This model has been developed for the purpose of studying the effects of HEMP illumination on an interconnected power system. The model provides the ability to predict the response of the electric power system to an EMP [2]. The paper presents the model and preliminary results obtained with the model. Specifically, a parametric study was conducted to obtain the effects of; the grounding system [3], soil resistivity, line construction, and EMP orientation.

References

1. "Power System Transient Simulation Program (PSTS) - Users Manual," Georgia Tech.

2. "Nuclear Electromagnetic Pulse (EMP) and Electric Power Systems," P.R. Barnes, E.F. Vance and H.W. Askins, ORNL-6033 Report, April 1984.

3. "Transient Analysis of Grounding Systems," A.P. Meliopoulos and M.G. Moharam, IEEE-TPAS, Vol. 102, No. 2, February 1983, pp. 398-399.

HEMP INTERACTION WITH AN ELECTRIC
POWER DISTRIBUTION CIRCUIT

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ABSTRACT

A high altitude nuclear burst, detonated at a height of 50 km or more causes two types of electromagnetic pulses, high altitude EMP (HEMP) and magneto-hydrodynamic EMP, which will interact with electric power systems. Previous work {1} indicated that millions of miles of electric distribution systems in the United States may be especially vulnerable to HEMP incident simultaneously throughout large portions of the United States. The purpose of this work {2} was to perform an initial assessment of HEMP induced surges on a simplified electric distribution system. This report presents the assumptions, methodology, and resulting induced transient voltages and current at various points in the distribution circuit in the microsecond timeframe, considering the impacts of HEMP incident simultaneously throughout the distribution system for a range of parametric conditions.

The results of this work suggest that EMP could induce voltage transients that far exceed the basic insulation level (BIL) of distribution systems and that a more detailed analysis is warranted.

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1. Zaininger, H.W. *Electromagnetic Pulse (EMP) Interaction with Electric Power Systems,* Oak Ridge National Laboratory, ORNL/Sub/82-47905/1, April 1984.

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HEMP-Induced Transients in Transmission and Distribution (T&D) Lines

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ABSTRACT

The corona effects on the early-time induced transients on the transmission and distribution (T&D) lines are calculated based on two different corona models; namely, the Townsend model and the conductivity model. Three different sources of excitation of the lines are considered, which include a HEMP plane wave, a localized voltage source, and a current injected at a point on the wire. The induced current and charge are calculated and compared with some available experimental data and with the results of Baum's model. The results illustrate that the corona generally reduces the peak value of the induced current as much as 30% of the value and decreases the rate of rise by about 40%.

The HEMP-induced stresses across dielectric insulators in some typical electric power systems are also calculated. The insulators that are considered are line supports in T&D line poles, and transformer bushings in distribution and power transformers. Different elevation and azimuthal angles of HEMP incidence with two different values of ground conductivity are considered. The HEMP-induced "potential difference" across the line support and air gap in the transmission lines and the HEMP-induced open-circuit voltage across transformer bushings are calculated. The "potential difference" across the line support and across the air gap can be as high as 7 MV. The rise time of the "potential difference" is about 110 ns, and the fall time is about 2-3 μs. The open-circuit voltage across transformer bushings can be as large as few tens of MVs and the rise time is in the order of 100 ns and the fall time 800 ns.

MULTIPLE PARALLEL WIRES ABOVE A FINITELY CONDUCTING PLANE EARTH IN THE PRESENCE OF A PLANE WAVE (EMP)*

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Abstract

The time-domain current induced in infinitely long, highly conducting, parallel wires above a finitely conducting plane earth in the presence of a plane electromagnetic wave is investigated. The plane wave is assumed to have its magetic field perpendicular to the axis of the wires, and takes the time-domain form of a double-exponential pulse. Results indicate that the currents are generally smaller than that induced in an isolated conductor because of the coupling between wires and the ground reflection.

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*Research reported in this Note was sponsored by the Division of Electric Energy System, U.S. Department of Energy, and was performed at the Oak Ridge National Laboratory under Contract No. DE-AC05-840R21400 with Martin Marietta Energy Systems, Inc.

EMP-INDUCED CURRENTS ON WIRE ABOVE GROUND

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ABSTRACT

The coupling between a plane-wave EMP and an infinite thin wire above a homogeneous ground is studied. The coupling between the wire and ground contains no approximations other than the thin-wire approximation. This demands numerical integration and we use suitable quadrature formulas with a high degree of accuracy. To get the time-domain response we use a standard FFT (Fast Fourier Transform) routine.

Parameters like wire height, angles of incidence, soil conductivity etc can be freely varied and we discuss extreme parameter values. The pulse shape is also varied.

The numerical integration needed for finite soil conductivities is quite time consuming. We propose, therefore, a simplyfied scheme where the incoming EMP is correctly reflected in the soil but where the scattered field from the wire is either not reflected (soil absent in wire-soil impedance) or perfectly reflected. This gives a lower and an upper bound for the current.

We use our results also to discuss the usefulness of transmission-line approximations for the wire and earth system.

Reference: L. Jönsson, S. Westerberg: EMP-induced currents on wire above ground, internal report FOA3 (Swedish National Defence Research Institute dep. 3, Box 1165, S-581 11 Linköping, Sweden), 1985, not published.

EMP COUPLING ON OVERHEAD CABLES REVISTED

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ABSTRACT

Rigorous analytical solution of the problem of EMP coupling on overhead cables, reveals that maximum coupling takes place when the critical parameters (length ℓ, height h, and angles ψ and ϕ) satisfy the conditions:

$$\tan\phi = \frac{\left[\sqrt{E_{Ho}^2 + E_{Vo}^2} - E_{Vo}\cos\psi\right] E_{Ho}\sin\psi}{E_{Ho}^2\cos\psi + E_{Vo}\sqrt{E_{Ho}^2 + E_{Vo}^2}\,\sin^2\psi} \quad (1)$$

$$2\,h\sin\psi = (1 - \cos\phi\cos\psi)\,\ell \quad (2)$$

$$r = \frac{2\,h}{\ell} = \frac{E_{Ho}^2 + E_{Vo}^2 - E_{Vo}\sqrt{E_{Ho}^2 + E_{Vo}^2}\,\cos\psi}{E_{Ho}^2 + E_{Vo}^2\sin^2\psi}\,\sin\psi \quad (3)$$

E_{Ho} and E_{Vo} are the horizontally and vertically polarized components of the EMP electric field.

These conditions result in significant changes (relative to old solutions) in the level of EMP-induced transients when the elevation angle of incidence ψ is near zero.

*Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under Contract No. DE-AC05-84OR21400.

THE RESPONSE OF ABOVE-GROUND LINES TO TRANSIENT ELECTROMAGNETIC FIELD EXCITATION

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Abstract

This paper discusses some of the calculational models which can be used to estimate the response of overhead lines, such as power transmission or distribution lines, to transient electromagnetic (EM) field excitation. This excitation could appear in the form of a plane wave, as in the case of high altitude EMP, or as a radiating spherical wave, formed by a localized lightning discharge. In both cases, it is possible to formulate the solution for the induced current in an integral equation form for a rigorous solution, or one can use a transmission line approach for determining an approximate, yet surprisingly accurate, solution.

In this paper, the transmission line approach for solving these EM coupling problems is discussed, and the results of several different calculations are presented.

ON THE FRONT-OF-WAVE OF EMP INDUCED POWER LINE SURGES*

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ABSTRACT

An important characteristic of electromagnetic pulse (EMP) induced transients if the front-of-wave (FOW) which describes the rate of rise, time to reach peak amplitude, and the value of the peak amplitude. For overhead transmission and distribution lines, FOW depends on the angle of incidence, ground characteristics, height of the line above the ground, and EMP wave polarization and time history. An upper bound to the rate-of-rise of the induced surge can be obtained by selecting a single exponential function of time to represent the EMP wave form. The results of a parametric study on the FOW and EMP power line transients are discussed in the presentation.

*Research sponsored by the Office of Energy Storage and Distribution, Electric Energy Systems Program, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

Effect of Corona on the Response of Infinite-Length Transmission Lines to Incident Plane Waves

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Abstract

This paper applies a simple breakdown model of the corona around a wire to calculate the response of the corona and wire (charge per unit length and current) to an incident transient electromagnetic plane wave. This wire is assumed to be perfectly conducting and of infinite length. It may be in free space or parallel to a ground plane. A transmission-line approximation is used for these calculations.

AN EXPERIMENT TO DETERMINE THE EFFECTS OF CORONA ON THE EMP RESPONSE OF A CONDUCTING LINE*

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Abstract

Using a corona model described by Carl Baum [1], an experiment is proposed to examine the effects of corona on a conducting line suspended in free space at a known angle with respect to the E-field of a high altitude electromagnetic pulse (HEMP). Various parameters of Baum's model are analyzed in terms of their impact on corona formation. An experiment design to maximize corona effects is discussed. Since the experiment will be conducted sometime in April or May, 1986, this presentation will include an up-to-the-minute discussion of the results of the experiment.

Reference

1. Baum, C.E., "Effects of Corona on the Response of Infinite-Length Transmission Lines to Incident Plane Waves", EMP Interaction Note 443, Air Force Weapons Laboratory, Albuquerque, NM, February 1985.

*Research sponsored by the Office of Energy Storage and Distribution, US Department of Energy, and was performed under subcontract number 19X-027461C with Martin Marietta Energy Systems, Inc.

A WIDE BANDWIDTH ELECTRIC FIELD SENSOR FOR LOSSY MEDIA

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Methods for measurement of the electric field in lossy media have been addressed by a number of authors (Ref. 1-5). The sensor described in the referenced papers have been dipole designs which measure one component of the electric field. To achieve proper calibration and wide bandwidth, matching of the impedence of the sensor to the media in which the electric field is to be measured is required. In this paper we describe a wide band electric field sensor which measures the two orthogonal components of the field, and which can be used in media with a wide range of conductivities.The sensor design consists of five parallel conductors (Cu tubes in our first implementation of the design), arranged on a dielectric cross with the conductors perpendiculr to the plane of the cross. The tubes at each of the four ends of the cross are connected through resistor strings to a rod at the center of the cross, which serves as a common reference point for the measurements. The lower portion of each resistor string is a 50 ohm resistor. The voltages across the two 50 ohm resistors associated with one plane of the conducting rods are subtracted in a balun to give a measure of the average electric field between the rods. Similarly, the resistors associated with the other plane provide a measure of the electric field in the orthogonal direction. Measurements of electric fields in soil (10^{-2} s/m) have been performed with this sensor, and the risetime was found to be faster than the pulsed electric field (approximately 7 nsec.)

References

1. C. E. Baum, Sensor and Simulation Note #13.
2. C. E. Baum, Sensor and Simulation Note #15.
3. C. E. Baum, Sensor and Simulation Note #19.
4. C. E. Baum, Sensor and Simulation Note #26.
5. C. E. Baum, Sensor and Simulation Note #33.

An Automated Measurement Probe Verification System (PVS)

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EG&G Washington Analytical Services Center, Inc., has developed a hardware application for the Naval Sea Systems Command which automates the status verification of measurement probes used for signal detection in support of EMP testing.

The concept of probe verification relies on the transmission of a known signal into a data link and subsequent measurement and characterization of the resulting signal to determine the status of the connected probe. The transmitted signal is passively perturbed by the electrical personality of the probe resulting in a distinct waveform. Comparison of the resulting waveform with an expected norm for the specific probe indicates whether the probe is electrically shorted or open, mechanically closed or open, not connected to the data link, or not the correct probe type. In addition to the status of the probe, data used for the calculation of several other parameters such as DC offset, RMS or average noise, and system gain calibration can be acquired and the resulting values passed to an external data acquisition system for inclusion in the corrections applied to acquired data.

The system consists of a low speed digitizing oscilloscope for acquisition of the referenced signal and a high speed, 16-bit instrument controller to examine and characterize the acquired data using a combination of custom and commercial software. In order to maximize throughput, the controller directs the digitizer to acquire new waveforms while concurrently processing, or displaying previously acquired data. Waveforms which indicate a problem can be redisplayed on the oscilloscope's display for operator intervention. The controller provides additional operator interaction and control through its display and keypad.

Information concerning the address of the data link, input address on a remote transmitter, and the type of measurement probe are passed to the PVS either manually or via a remote link from an external data acquisition system. This information is used by the PVS to command a multichannel data link control unit for the purpose of establishing the link status necessary for verification.

This work was sponsored by the U.S. Naval Sea Systems Command under Contract N00024-84-C-5357.

PROCESSING, EVALUATION AND ANALYSIS OF THE MAGNETIC FIELD DATA ACQUIRED BY THE F 106-B NOSE BOOM SENSOR

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Abstract

The theoretical considerations useful in designing an airborne platform for transient or broadband CW electromagnetic field measurement have been reported in the past [1]. These considerations were applied in specifically designing a nose boom B-dot sensor for the NASA F 106-B aircraft [2]. Based on this design and some refinements, such a sensor was procured by the Air Force Weapons Laboratory and extensive data gathered during the EMP testing of the aircraft in February-March 1984.

This paper presents the results of processing and analysis of the data. Some additional processing methods which appear possible in future efforts of this nature are also indicated.

[1] D.V. Giri and C.E. Baum, "Airborne Platform for Measurement of Transient or Broadband CW Electromagnetic Fields," Sensor and Simulation Note 284, 22 May 1984.

[2] D.V. Giri and S.H. Sands, "Design of Incident Field B-Dot Sensor for the Nose Boom of NASA F 106-B Aircraft," EM Platform Memo 1, 5 September 1983.

EFFECTS OF AIRCRAFT INTERACTION ON PERFORMANCE OF B-DOT SENSOR FOR DELTA-WING AND CARGO-TYPE AIRCRAFT

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When an aircraft is used as an airborne platform for supporting an electromagnetic sensor, the aircraft will introduce field distortion and thus affect the measurement accuracy. Any object, metallic or dielectric, will produce scattering, but the effects of scattering may be minimized by properly choosing the location for the sensor. Theoretical considerations using simplified models suggest that to measure a horizontal magnetic field parallel to the fuselage, for example, the best location for the sensor are in the plane of symmetry of the aircraft, either at at the nose or aft of the aircraft, and near the axis of the fuselage.

The precise location of the sensor can for simplified aircraft geometries be determined by calculations, but for more complex shapes scale model measurements can be used.

In this talk results of scale model measurement study to determine the optimum location of the sensor as well as sensor performance are presented. The examples presented are for a delta wing aircraft with sensor mounted forward of the aircraft and for a twin engine cargo aircraft with the sensor mounted at the aft.

Recent Fiber Optic Data Link Developments

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The past four years have seen many improvements in conventional LED-based, wide-band, analog, fiber-optic (FO) telemetry links used in the acquisition of EMP data. EG&G has incorporated an eight-input relay tree into the front end of a remotely controlled FO transmitter. A single controller operates up to eight such transmitters, providing pre-instrumentation of up to 64 inputs. Each FO transmitter contains a microprocessor to handle command and verify communication with the controller and to implement remote commands. Each FO transmitter also contains programmable attenuators and amplifiers to provide a selectable system gain from -64 to +40 dB in 2-dB steps. An internal calibration generator in the FO transmitter may also be switched in either with or without the input signal providing both link gain and sensor connection verification. One version of the FO transmitter also provides a remotely selectable one microsecond integrator to provide direct connection to a derivative output sensor. The FO telemetry link band pass (-3 dB points) has been extended to cover from 1 kHz to 150 MHz, and the dynamic range has been increased to 47 dB.

SOME ISSUES ON DATA CORRECTIONS: DATA COMPENSATION AND NOISE

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This paper is divided into two parts. In the first part, a comparison and analysis between raw and compensated EMP peak values show that

1. Differences between the raw and compensated data are small, and,

2. We can replace this complicated process of compensation by a simple procedure with little error.

In order to perform accurate post-test analysis, one must correct for the errors introduced by instrumentation and digitization. The second part of the paper discusses several procedures for integrations and Fourier transform of time-domain data to deal with static noise and digitization errors. Also a model is used to estimate the effect of digitization miss on the signal spectrum.

RETRIEVAL OF TIME DOMAIN PULSE FROM MAGNITUDE SPECTRUM IN EMP FLOWDOWN ANALYSIS

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A Hilbert transform algorithm has been developed using an impulse train technique under the minimum phase condition, and applied to reconstruct the time domain EMP response from the magnitude spectrum alone.

Electromagnetic pulse analysis is often necessary to predict and characterize the EMP induced threats at the various points of electronic systems, such as the surface current density on the subsystem enclosure, or pin threats on the cable connectors, etc. Due to the complex nature of the wide band EMP energy coupling problems, the flowdown analysis is commonly performed in the frequency domain using only the magnitude spectrum and ignoring the phase informations. Therefore, the analysis results are restricted to only the magnitude spectrum. It is, sometimes, required to know the time responses, of the results, such as the open circuit voltages and the short circuit currents.

If a complex function in a frequency domain is analytic and satisfies the minimum phase condition, its real and imaginary components are related by the Hilbert transform integral. The inverse Fourier transform of the complex function will result in a real, casual and stable time domain response. The characteristic of a time domain signal which satisfies the minimum phase condition is that most actions take place early in the time and approach to zero as time increases. Most EMP responses are in this category and satisfy the minimum phase condition. This transform algorithm takes the advantage of the characteristics of the EMP signal. The phase spectrum can be obtained from the magnitude spectrum using the Hilbert transform integral which is a convolution of a Kernel function and a 1/f function. The Kernel function contains the magnitude informations. The convolution and its properties are the key points of the impulse train technique which can evaluate the integral fast with accurate results. The phase spectrum is expressed as

$$\hat{X}_I(f) = -\frac{1}{\pi} \sum_{n=1}^{N} A_n[(f-f_n)\ell n|f-f_n| + (f+f_n)\ \ell n|f+f_n|]$$

where A_n is the coefficients of the logarithm of magnitude spectrum, $\hat{X}_R(f)$, and N is the total sample number . The magnitude spectrum and the reconstructed phase spectrum are inverse Fourier transformed to obtain its time response.

This code has been tested and provided very accurate results when the function satisfied the minimum phase condition. It has been effectively utilized to retrieve time domain responses from the magnitude spectrum in most of the EMP flowdown analysis.

A NOVEL TECHNIQUE OF PREPROCESSING NOISY DATA FOR A PRONY ANALYSIS

By
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ABSTRACT

Generally when an electrical system is illuminated by an electromagnetic pulse (EMP), such as the nuclear EMP or a lightning EMP, the induced currents and voltages are the superpositions of damped sinusoids. Moreover, the scattered field is also a superposition of damped sinusoids. Consequently, EMP test data can be expressed simply in terms of the damped sinusoid parameters. A technique for obtaining these parameters was developed in 1795 by the French mathematician Prony (1). This technique became a practical reality only with the advent of high speed digital computers.

When the Prony method is applied to precise time domain data, accurate results are generally obtained. However, if even a small error (< 1%) is introduced in the data, the Prony method suffers from instability and inaccuracy. As a result, a number of alternative approaches have been investigated (2). The most promising techniques appear to be the basic Prony applied to data that has been preprocessed.

The novel technique that is developed here for preprocessing noisy data to be analyzed by the Prony method involves using an effective "noise filter" formed by a harmonic expansion of the data waveform. A serial correlation calculation is used to determine the relative randomness of the error between the harmonic expansion and the data waveform on a point-by-point comparison. An optimum order for the harmonic expansion is selected on the basis of a minimum correlation. This optimum expansion represents a noise-reduced waveform which allows the use of Prony analysis on noisy data with signal-to-noise ratios as small as 20dB.

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TRANSIENT INSTRUMENTATION CORRECTION

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The use of CW instrumentation calibration data to perform corrections to transient EMP data has led to the development of spacial algorithms to handle the zero frequency component of the measured response. This has evolved from the appliction of linear systems theory as developed for steady state responses. In this approach the system is represented as $M(\omega)=H(\omega)S(\omega)$ where $M(\omega)$ is the frequency domain representation of the measured signal, $H(\omega)$ is the instrumentatio "transfer" function and $S(\omega)$ is the frequency domain representation of the system input. This formaulation is derived from the infinite Fourier transform of the convolution integral defining the measured response in terms of the system inpulse response $m(t)=h(t-t)*s(t)$ which reduces the steady state formulation if $h(t)$ is a function or if the signal duration is very long with respect to the duration of $h(t)$. However, in the case of EMP transients and typical current probes, the probe impulse response is a factor of ten greater then the signal duration. Use of the steady state formulation leads to a numerical and mathematical problem at the zero frequency component of the measurement when attempting to obtain $S(\omega)$ by division. The finite duration of the signal must be taken into account and the finite Fourier transform of the convolution over the signal duration T leads to $M(\omega,T)=H(\omega,T)*S(\omega,T)$. The effective duration ot the impulse response of a band pass probe is the period of the lower break frequency. The net area under the impulse response is zero when integrated to 2 or 3 times the effective period. In the case of EMP type probes, this occurs at 100 KHz which has a period 10 s. Trunction of the signal typically occurs around 1-2 s and the effect is to introduce a zero frequency component into $H(\omega)$ representing the net area of the truncated impulse response. When properly computed, the singularity at the zero frequency component is remove.

The proper method of computing the instrumentation correction is to inverse Fourier transform the CW calibration data to obtain the the impulse response. This response is then truncated at time T and sampled at the oqiginal sampling rate of the data. The truncated and sampled impulse response is then Fourier transformed to obtain $H(\omega,T)$ for use in linear systems formulation.

Data will be presented which illustrate the effects of using the proper instrumentation compared to the classical approach of using the CW calibration data.

EVALUATION OF DATA ERRORS INTRODUCED

BY NOISE, SAMPLING RATES AND COMPOSITE WAVEFORMS

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Abstract

This paper evaluates the errors introduced by instrumentation noise, digital sampling rates and composite waveforms generated from multiple digitizer records used to record long duration events. Individual and combined errors are evaluated as well as their impact on analysis and conclusions.

Analytical waveforms representative of the frequencies and damping factors normally experienced during EMP testing of aircraft are used to demonstrate and quantify the errors introduced by instrumentation noise and sampling rates. Effects of noise on composite waveforms using time tieing of multiple data sets well as the limitations imposed on the use of this noisy data are also evaluated.

Comparisions of the results using the analytical waveforms are made with actual waveforms having similar characteristics. Differences between analytical and actual waveforms are analyzed to determine the applicability and limitations of these results for aircraft EMP test data.

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A METHODOLOGY TO ASSESS THE EFFECTS OF EMP ON CIVILIAN ELECTRIC POWER SYSTEMS*

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ABSTRACT

This paper presents an overview of an assessment methodology developed to explore the possible effects of high-altitude EMP interaction with civilian electric power systems. The methodology is applicable to both equipment and system-level response(s) due to early-time HEMP and later-time MHD-EMP.

The HEMP assessment methodology allows the use of spatially distributed, EMP environmental specifications to estimate system response of large, interconnected electric utility grids. Stress to strength comparisons are used at the device/equipment level. Risk assessment, "fault tree" analysis techniques are employed to investigate facility and subsystem performance. System-level assessments are accomplished using existing load flow and transient stability codes.

The MHD-EMP assessment methodology has been developed from known techniques to investigate the response of electric power systems to geomagnetic storms. Low-frequency, circulating currents, induced in the power system, are estimated by network analysis. Equipment analysis focuses on the possible overexcitation of power and instrument transformers. System-level assessments incorporate the consequential effects due to overexcitation. Such effects may include: increased system reactive power requirements, reduced bus voltage(s), and power-frequency harmonic generation.

*Research sponsored by the Division of Electric Energy Systems, United States Department of Energy, through the Oak Ridge National Laboratory, Subcontract No. 15X-43374C.

SIMULATED MHD-EMP INTERACTION WITH AN ELECTRIC POWER SYSTEM*

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ABSTRACT

The magnetohydrodynamic electromagnetic pulse (MHD-EMP) environment created by a high-altitude nuclear event is quasi-dc in nature and closely resembles the environment produced by geomagnetic storm phenomena. Analysis of the time domain and frequency domain components of the MHD-EMP electric field show that the MHD-EMP environment and severe geomagnetic storm environment are similar. The only significant difference between the two environments is the direction of the electric field. The MHD-EMP event produces a non-conservative electric field, versus the east-to-west direction (in North America) of the geomagnetic storm induced electric field with increasing magnitude from south to north.

The electric fields produced by MHD-EMP interact with electric power systems to produce d.c. currents in the power lines. The effects of the MHD-EMP from two simulated high-altitude nuclear events on an electric power system are assessed using a methodology that parallels the methodology developed to assess the effects of geomagnetic-induced currents (GIC). The transmission and subtransmission power systems, 500 kV to 69 kV, are modeled. The d.c. currents induced in the power system are shown to be larger than the GIC produced by severe geomagnetic storm disturbances for one of the MHD-EMP events and smaller for the other MHD-EMP event. The difference in the MHD-EMP effects is explained by the location of the high-altitude nuclear event relative to the power system.

*Research sponsored by the Division of Electric Energy Systems, United States Department of Energy, through the Oak Ridge National Laboratory, Subcontract No. 15X-43374C.

EMP EXPERIMENTAL TESTS ON LARGE
ELECTRIC POWER APPARATUS*

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ABSTRACT

There are little data available on the response of electric power apparatus to EMP. These data are necessary to the assessment of EMP on electric utilities.

The philosophy of the selection of the tests and of the equipment to be tested are discussed. Experiments are described to provide data for determining equivalent circuits, or voltage and current transfer functions for power apparatus such as transformers. Selected results of these experiments are given.

*Research sponsored by the Division of Electric Energy Systems, United States Department of Energy, through the Oak Ridge National Laboratory, Subcontract No. 15X-43374C.

ASSESS THE IMPACT OF STEEP FRONT, SHORT DURATION IMPULSE ON POWER SYSTEM INSULATION--A REVIEW OF PROGRESS TO DATE*

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ABSTRACT

This paper discusses the results to date of a project to assess the impact of steep front, short duration (SFSD) impulse on insulation systems, in particular power systems insulation. The Phase I effort of the project has produced an extensive listing of references (1940-date) covering the open literature and selected unclassified results from restricted sources. A summary of the overall content of this listing is presented. In particular, results of experimental investigations and anomalous failures of power system insulation systems are given.

Known sources of SFSD impulse, including both natural and man-made, are discussed. The shapes of these SFSD impulses are compared to the "standard" test pulses used in qualifying power system apparatus. The rationale for the selection of three pulse shapes for further experimental investigation of power systems insulation response is examined and the parameters of the pulses are presented.

A comparison of power systems apparatus reflecting the vulnerability of the apparatus' associated insulation system to SFSD impulse and the relative ease of replacement of the apparatus is summarized and a program for future research (Phase II) is outlined.

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*Research sponsored by the Office of Energy Storage and Distribution, Electric Energy Systems Program, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

EFFECT OF EARLY TIME HEMP ON POWER EQUIPMENT
AN INITIAL EVALUATION

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ABSTRACT

The early time HEMP induced voltages on transmission and distribution lines throughout the continental USA are calculated and compared to equipment insulation levels to produce an initial assessment of the systems which are most vulnerable to early time HEMP.

*Research sponsored by the Division of Electric Energy Systems, United States Department of Energy, through the Oak Ridge National Laboratory, Subcontract No. 15X-43374C.

ANALYSIS OF TRANSIENT ELECTROMAGNETIC FIELDS IN COMMERCIAL POWER SUBSTATIONS

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Power outages can result from damage or misoperation in switchyards caused when high-voltage switching transients are coupled into sensitive substation protective circuits. Having EMP-like characteristics, these transients can be caused by normal switching operations as well as faults. A timely understanding and solution to this problem is important for two reasons. First, to meet the increasing demand of consummers, the power industry is raising the voltages of transmission lines thus increasing the amplitudes of switching transients. Second, more sensitive microprocessor- based controllers are being utilized in modern substation protective circuits thus increasing their potential susceptibility to EMI effects. This paper describes an approach currently being employed to develop and validate a model which will be used to predict and reduce effects of electromagnetic interference caused by switching phenomena in high-voltage substations. The appropriateness of advanced electromagnetic modelling and computer-controlled data acquisition techniques developed for EMP coupling assessments on aerospace systems to the solution of this problem will be reviewed.

This work is being sponsored by the Electric Power Research Institute (EPRI), Palo Alto, Ca. Subcontractor support is being provided by McGraw-Edison, Canonsburg,Pa. and Mississippi State University.

EMP effect on the electronic equipment of a HV substation

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It is generally admitted that the peak value of the overvoltages induced by an EMP on a HV line are of the order of magnitude of those produced by a lightning stroke. With the exception that an EMP can illuminate simultaneously the whole network of a country, its effects on the HV electrical material should be comparable to those due to lightning strokes.

However in a HV substation there is an electronic equipment used for control and protection such as microprocessors for the HV network management, electronic relays, alarms,etc. This equipment receives information and sends commands through lines having tens or hundreds of meters of length which can act as antennas for an electromagnetic field and peak up significant disturbances due to an EMP.

The aim of this paper is to estimate the level of such disturbances and their effect on the electronic equipment using a numerical simulation based on computer codes.

Three penetration paths have been choosen in order to put into evidence the consequences of such a phenomena : a connection from a bay cubicle of the substation to the equipment situated in the main building, a connection inside the building and a coaxial transmission in the ground wire.

Transient voltages with peak values up to about 40 kV at the entry of the electronic equipment have been found for the first case if no protection measures are provided (non-shielded conductors, no suppressors). The situation prooved to be less critical for the two other cases, due to the attenuation provided by the building and by the sheath of the coaxial transmission placed in the ground wire.

In the conclusion possible protection measures are briefly discussed.

UNCOMMON DEVICES TO PROTECT FACILITIES FROM VERY HIGH LEVEL TRANSIENTS INDUCED ON POWER LINE BY LIGHTNING OR EMP

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ABSTRACT

In lightning or EMP protection problems it is sometimes necessary to take into account very high transients collected by the commercial power line. These high transients may occur in cases of direct lightning strikes on the line, or in cases of EMP due to low altitude burst or ground burst close to the line. In theses cases the common protection devices with sparkgaps are not sufficient when the energy to absorb is higher than a few tens kJ.

The presentation will discuss the limitations of usual protection devices, the threat level in extreme cases and will present three different uncommon devices to preserve the inside of a protected aera from the transients collected outside. These devices have been qualified and some results of test will be presented.

The first device is composed of an AC or DC motor and an AC generator joined by and insulating shaft. The special design of the shaft allows to get a very high insulation beetween the outside of the protected aera ("dirty side") and the inside ("clean side"). This device is suitable for small power up to 5 kVA and must be installed through the wall of a Faraday cage.

The second device is an hydraulic system composed of an AC motor with an hydraulic pump. The high pressure oil flows through the liner of the Faraday cage. Inside of the protected aera are installed an hydraulic motor and an AC generator. This device has been qualified for a power of 100 kVA but the same principle can be applied for higher power. The insulation level is not directly dependant on the power.

The third device allows to improve significantly an existing protection based on sparkgaps or can be included in a new design. In very severe environnement, protection devices may have to withstand several direct lightning strikes or very energetic EMP transients. The improvement of arresters energy capability consists in a very fast circuit shorter with an adequate command device. This protection system is available for single phase or three phases. It needs no auxiliary power supply because it uses a part of the energy of the discharge current to action the circuit shorter. The operating power is not limited by the protection device (up to several hundreds kVA).

These three uncommon devices have many advantages : high energy capability to absorb extreme EMP or lightning transients, simple and sound design, low maintenance cost, and they may replace or improve usual protection devices based on surge arresters and filters.

ARE THERE BLACKOUTS IN OUR FUTURE?

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We have just passed the twentieth anniversary of the Northeast Blackout of 1965. What has happened in the interim to power systems, their construction and operation, that would make us more or less susceptible to recurrences of that event?

There have been changes in the economic situation, in the sensitivity to the environment, in the state of the technology and in the relationships between government and the regulated industry. All of these changes in the past two decades have had, and will have, effects on the ability of utility systems to withstand disturbances — whatever the source.

The good, and not so good, differences between the present situation and that of 1965 are discussed, along with projections of future reliability. The effect of multiple disturbances is described, and the consequences of the ever-present laws of Murphy are considered.

Pulse Injection on a Power Plant.

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In order to investigate the propagation of a conducted pulse in a power plant, pulse injection was used as a test method on a Swedish power plant.
A 100 kV pulse generator was coupled to the system at three different points: to the switchyard, to a 200 meter long power line and directly to the main transformer. The current measurements that were made in and at points adjoining the switchyard delivered data for the calculation of the transfer function, the peak current attenuation and the current distribution of the switchyard. By combining these data with the results from the measurements on a 200 meter long power line, it was also possible to estimate the effect of a switchyard on a conducted pulse nearby a power installation.
The pulse injection setup at the main transformer was designed to give a well defined double exponential pulse at the transformer input. Current and voltage were measured at the transformer input and output, and by applying a Fourier transform to the time domain data, the input impedance and the transfer functions could be calculated.
Finally, measurements were made at several points of the control system. Peak levels and charachteristic frequencies were detected and analyzed.
The results indicate that the switchyard has an attenuating effect on the peak current value by one order of magnitude. Due to the bushing at the transformer input, the same attenuation was observed for the main transformer.

Historical Summary of Resonance Extraction In General and Prony's Method In Particular

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Since 1974 a quest, of sorts, has been on to find the ideal signal processing algorithm to extract the singularity expansion parameters from measured test data (electromagnetics). Investigation of parameter extraction in both the time and frequency domain have been studied. Accusations of windmill jousting rose (particularly from the pure signal processing experts), but did not slow down the search for the ideal algorithms. Techniques such as Prony's method, Pencil of Functions, and recursive least squares techniques have all been used. It has since been shown that almost all techniques are variations on Prony's method.

Many specific issues relating to the mathematical expression and the physical understanding of the interaction process have been studied over the years. Such problems as signal-to-noise ratio, rank of the system, and existence of an entire function have all been looked at and a lot of insight has been gained.

This paper will present an historical synopsis of this quest. An attempt will be made to illuminate all the high and low points of the studies over the years. In addition this author's biased view of the issues will be presented.

USE OF COMPLEX DEMODULATION IN ANALYZING DAMPED SINE WAVE RESPONSES

H. T. Davis

An electromagnetic pulse (EMP) incident on an aircraft system induces currents on the skin, which then couple through points of entry in the surface to induce currents on the wires connected to electronic components inside the aircraft. The currents are of short duration, typically 2 to 5 us, and are typically sampled at interals of 1 to 20 ns. For any meaningful analysis, the data have to be converted into physical parameters. The singularity expansion method (SEM) provides a reasonable way to parameterize the system response.

The SEM introduced by Baum provides a physically meaningful way to characterize a conducting body's response to EMP. The response of a conducting body to an incident EMP wave is expressed as a sum of complex exponentials using parameters related to the natural modes of the conducting body. This parameterization not only reduces the amount of data required to characterize a sample realization, but also reduces it to terms that are physically useful. Ideally, the parameters can be predicted from models of the aircraft surface. However, the complexity of an aircraft surface makes it difficult to formulate and solve the scattering problem for an exact aircraft model. Therefore, simplified models, which preserve the global features of the aircraft, are used to obtain mathematically tractable solutions. This makes it important to have numerical methods of estimating the natural modes from data.

A method of estimating the natural modes from the data, complex demodulation, is presented in this presentation. The sensitivity of complex demodulation to noise is discussed. Application to more complex problems, such as spatial filtering to estimate natural modes, is also discussed.

SIGNAL PROCESSING AND ANALYSIS OF F-106B SIMULATED EMP DATA

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Since 1979, the NASA Langley Research Center has been investigating aircraft/lightning interaction processes with a specially instrumented F-106B aircraft [1]. In February and March, 1984, the F-106B was used in an extensive series of simulated EMP tests at the Air Force Weapons Laboratory (AFWL). Data was taken at test points both external and internal to the aircraft in two aircraft modes: *fly-by* and *test stand.*

In this paper, we analyse a subset of this data at test points exterior to the aircraft. We process the data using the interactive signal processing algorithm SIG [2]. We develop a consistent procedure for the processing of the data, consisting of mean removal, filtering, decimation, and windowing. From free-field data and data taken at various test points on the exterior of the aircraft, we develop a transfer function for test point response by several methods: First, a Weiner filter, contained in SIG; second, a pole-zero filter, included in the non-linear optimization algorithm NLS [3]; third, direct frequency domain division. We discuss results from these three methods and adopt the NLS method as a standard.

The creation of test point transfer functions allows us to examine several features of the data, including aircraft resonances. The resonances are identified with NLS, using several different filtering strategies to isolate various portions of the frequency spectrum. We conclude with a discussion of the significance of the resonances and also comment on the possibilities of identifying aircraft features by other methods recently appearing the literature [4].

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SEM Characterization of Thin-Wire Planar Symmetric Single Junction N-Arm Elements

It was over a decade ago that Baum (1) formulated the singularity expansion method SEM for the characterization of transient electromagnetic interaction. Since then the SEM has been used by a number of researchers to investigate the interation of transient excitations with a variety of thin-wire geometries. These investigations have been instrumental in providing the community with a conceptual framework for understanding EMP coupling to aircraft and for a qualitative appreciation of why certain aircraft sub-assemblies might be highly excited and others not.

This paper will present SEM poles, modes, and coupling coefficients for thin-wire planar symmetric single junction n-arm elements. Specifically, SEM data will be given for the tripole (a single junction three arm element with arm spacing of 120°), the symmetric cross, and the pentapole. Each of there geometrics exhibits one or more closely spaced pole pairs in the fundamental resonance region of the complex plane. Furthermore, it is possible to decompare the modal structures associated with these poles into a symmetric and anti-symmetric parts. It is our hope that the data presented here will stimulate thought and provide the catalyst for a more complete understanding of the fundamental physical mechanisms involved in electromagnetic interaction.

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A Priori Application of Results of Electromagnetic Theory to the Analysis of Electromagnetic Interaction Data

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Abstract

Since the introduction of the singularity expansion method (SEM) for the representation of transient and broadband electromagnetic interaction with general objects, there has been considerable attention given to associated analysis of electromagnetic-response experimental data to find the natural frequencies. Usually this has considered only single waveforms or frequency spectra for a parameter such as the surface current density at a particular position on the object under some particular excitation such as a particular direction of incidence with a particular polarization.

This paper explores several concepts for advancing the analysis of interaction data to obtain the various SEM and EEM (eigenmode expansion method) parameters. Basically the various properties of natural modes and eigenmodes are explored for application to the problem of the taking and analyzing of experimental data. Various techniques are explored including the enforcement of the SEM pole factors in multiple data records, separation of the modes by object symmetry, separation of the modes into E and H modes by measurement of surface charge density and equivalent magnetic charge density, and separation of the natural modes and natural frequencies by association with eigenmodes and use of eigenmode orthogonality. Basically these concepts involve application of a priori physics to the design of experiments and data analysis.

NUMERICAL METHODS OF NOISE REDUCTION FOR FREQUENCY DOMAIN SEM

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ABSTRACT

This talk addresses the numerical problem of performing a pole residue expansion on noisy frequency domain data. A method of combining dissimilar data sets to acheive increased accuracy in computing pole locations and residues is tested. The algorithm uses data sets consisting of responses of a radar target illuminated from different directions. Thus all data sets consist of frequency domain responses having the same poles but different residues. Computer generated data simulating scattering from a sphere and from a thin wire is corrupted with white Gaussian noise and the algorithm is tested for signal-to-noise ratios ranging from -10dB to 60dB. An iterative version of the algorithm is also presented.

A type of adaptive filter is also tested on single data sets of sphere and thin wire responses and compared with more traditional moving aperture filters. The proposed filtering scheme uses the known noise power level and an estimate of the local curvature in the data to formulate the optimal weighting window for each data point. Both the adaptive and moving aperture filters are tested on sparsely and densely sampled data sets. While both filters tend to improve the accuracy of the computed poles and residues with the dense data sets, the moving aperture filter severly degrades the accuracy on the sparse data sets. The adaptive filter however has little effect on accuracy for sparse data sets. Therefore, the adaptive filter will improve the accuracy of the computed poles and residues if the data set is dense enough and will not harm the accuracy if the data set is too sparse to benefit from filtering.

IDENTIFICATION OF TRANSIENT ELECTROMAGNETIC SYSTEMS USING MULTIPLE ASPECT ANGLE DATA

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To date, identification of transient electromagnetic systems has been primarily based on a scalar pole-zero difference equation model [1]. In such a model, the input-output data is restricted to a single input and a single output. Recently, a state-space formulation of transient electromagnetic scattering has been proposed [2]. The principle feature of the formulation is that it provides for identification incorporating data from multiple aspect angles around a scattering system. The mechanism is a single-input, multiple output (SIMO) linear model.

In this paper, we discuss the SIMO model and propose a method of incorporation of the early-time portion of the transient scattered signal. The result is a partitioned state-space model of the scattering process. We comment on the utility and limitations of the model. We also suggest several simpler, step-by-step procedures based upon partition of the transient waveforms into early and late time segments. We illustrate these ideas with transient range data associated with scattering from a conducting rectangular plate and with synthetic data associated with scattering from a hard acoustic sphere [3,4].

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Improved Estimation of SEM Parameters from Multiple Measurements

by

Sungwon Park *
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ABSTRACT

A problem of practical interests in electromagnetics is that of estimating the natural poles of a scatterer from transient surface current density measurements. Because measurements made at different locations or with different directions of incidence have the same poles, we can use multiple data sets efficiently to get an improvement in the estimate of natural poles. A currently existing simple technique for using multiple data sets is simply to compute poles for each data set and then average the results. Using an iterative preprocessing algorithm (IPA) [1], it is possible to process multiple data sets at the same time to get an improvement in pole estimation.

An iterative scheme to estimate coupling coefficients, and natural modes is introduced. Simulation results indicate that errors in the parameters decreased dramatically at the first iteration after an initial estimate.

Also the Cramer-Rao lower bound for the characteristic polynomial coefficients for given multiple data sets is calculated.

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GENERALIZED SEM/PRONY SIGNAL ANALYSIS FOR EMP DATA WITH TIME-DELAY THRESHOLDS

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A formalism for analyzing signals containing components with different time-delay onset thresholds is presented. The signal components thus have different arrival times as measured at a given point in a spatially extended system. In practice, the signal is expanded in a small number of "wavelets", each of which looks like a generic signal and each of which can start at an arbitrary point in time. The formalism generalizes SEM or Prony analysis, in which time-delay onset thresholds are difficult to treat. Such signals do arise in EMP tests of communications systems, for example. Various components of the signal do arrive at different times, and can often be identified with a different physical origin (antenna, cable, etc.). Thus, the expansion is physically motivated.

Technically, signals are expanded in a non-orthogonal overcomplete set of functions (wavelets) containing both translations and dilations in both time and frequency. Arbitrary integral (or nonintegral) power behavior turn on above the time-delay threshold producing arbitrary rise times is allowed. In the frequency variable, the wavelets are characterized by simple or multiple poles (or cuts) with exponentially varying residues (or discontinuities). Besides generalizing the Prony states, the formalism also provides a realization of Gabor coherent states and Aslaksen-Klauder-Grossmann-Morlet affine states. Because the class of functions is so rich, a signal expansion truncates quickly.

In this talk the formalism is briefly explained along with its mathematical background. Techniques for implementation are discussed and numerical examples are exhibited.

THEORETICAL CONSIDERATIONS FOR OPTIMAL POSITIONING OF PEAKING CAPACITOR ARMS ABOUT A MARX GENERATOR PARALLEL TO A GROUND PLANE

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and

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Abstract

The object of this paper is to develop theoretical considerations useful in determining the electromagnetically optimal positions for a specified number of peaking capacitor arms about a Marx generator parallel to a ground plane. One is faced with the problem of distributed peaking-capacitor design in pulse power systems. This peaking capacitor system not only has a circuit role in decreasing the rise time of the output pulse, but also an electromagnetic function to serve as a boundary for the fast output wave, isolating this wave from the inductive Marx generator.

To achieve optimal shielding of the Marx and reduce oscillation between the different peaker arms, constraints are imposed to assure equal voltages and currents on all peaker arms. Based on a two-dimensional model (a transmission-line approximation) optimal positions for the peaker arms meeting these constraints are derived. For the case of a large number of peaker arms this problem simplifies to the use of a conformal transformation with a correction for the peaker-arm spacing. This spacing allows some coupling between Marx and ground plane at high frequencies which can be simply approximately quantified.

FIELD-CONTAINING INDUCTORS

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and

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Abstract

Field-containing inductors are required in certain simulator applications e.g., elements of pulse shaping networks, terminators for transmission lines, etc. Typical coils such as solenoids have a large magnetic dipole moment resulting in excessive interfering magnetic fields. An improved design based on the traditional toroidal coil windings will be presented. This new design consisting of two windings is capable of higher voltage operation. Optimal shapes, energy and forces will also be discussed. The normalized plots of attainable inductance for varying geometrical parameters presented in this paper should prove useful in future designs and applications.

THE DISTRIBUTED SWITCH FOR LAUNCHING SPHERICAL WAVES

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Abstract

One way of launching a fast transient pulse in the TEM mode of a biconic (or monoconic) antenna geometry is to use a distributed source. This paper discusses and generalizes this concept to that of a distributed switch which can be incorporated in typical Marx/peaker geometries. Various shapes for this type of distributed source/switch will also be discussed.

Abstract

The Nearby TEM Horn as a Source of

Pulsed Electromagnetic Fields

by

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A Transverse Electromagnetic (TEM) horn can be used as a source of pulsed electromagnetic fields. At a test position within several meters of the horn's input one can generate relatively intense fields, whose risetime and duration may be controlled by the geometry and overall size of the horn. This paper discusses horns that produce pulses having durations of nanoseconds. Approximate methods are given for calculating the peak field intensities and pulse shapes. These are compared with measurements. Very near the horn, the pulse shape varies with distance; the pulse becomes longer as the distance decreases. This work will be useful for measurements of the response of electronic equipment to pulsed electromagnetic fields.

A LOW-COST NUCLEAR TEM FIELD SIMULATOR

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A low-cost pulse generator and parallel plate stripline have been designed, built, and demonstrated to simulate the transverse electromagnetic (TEM) field generated by a nuclear high altitude electromagnetic pulse (HEMP). The characteristics of the TEM field include a peak electric field magnitude of 50 kV/m, a risetime of 5 nsec, and a fall time (50% of peak) of 200 nsec.

The pulse generator consists of commercially available 30 kV capacitors, 800 V gas filled spark gaps, and a 50 kV power supply. The parallel plate stripline is constructed of copper and aluminum sheets and measures 61 cm high by 100 cm wide by 300 cm long. The parallel plate is terminated into a 110 ohm, 15 kV ceramic resistor. Pulse measurements are performed with a 100 MHz storage oscilloscope and a 40 kV, 75 MHz high voltage probe.

This nuclear TEM field simulator has proven useful for evaluating the HEMP effects on military ordnance and communication equipment with dimensions up to 0.5 m in height.

Abstract

Scale Model Electromagnetic Pulse Simulation Facility

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This paper describes a specially designed electromagnetic test facility that can measure the transient response of test objects to unipolar electromagnetic pulses. The facility has the capability to illuminate long, relatively thin test objects. Typical test objects are metallic cylinders or scale model aircraft with long wire antennas attached. The wires may be up to 18 m long. Incident fields have a rise time of 1 ns and a decay time constant of 5 ns. Specially constructed miniature sensors measure surface current densities on the test object. A 1 GHz fiber optics set sends sensor outputs from the test object to a transient digitizer controlled by a microcomputer. Sensors are calibrated in the known field of a monocone over a ground plane. This facility has been used to measure the response of a model aircraft with long trailing wire antennas.

AN INJECTION TECHNIQUE FOR PREDICTING COUPLING*

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The feasibility of using an injection technique to predict the receiving cross-section of test objects over broad bandwidths and wide incidence angles is being studied. The concept focuses on the familiar expression for receiving cross section,

$$\sigma = \underbrace{\frac{\lambda^2}{4\pi} G(f,\theta,\phi)}_{\text{Gain Factor}} \underbrace{\frac{4 R_{in} R_L}{|Z_{in} + Z_L|^2}}_{\text{Impedance Mismatch Factor}} \text{ Square Meters}$$

By measuring the Z_{in} and Z_L looking both directions at a pair of terminals, the impedance mismatch factor can be determined. Also, by regarding the test object as a transmitting antenna, the gain factor can be computed by injecting a known current at the terminals and measuring the near field around the test object, followed by a near → far field projection. Since the system is reciprocal for low levels, the transmitting and receiving gains are equal.

The measurement and data storage/management/processing problems are obviously massive, so clever analyses are needed to make the problems manageable. For example, σ is a highly structured function of frequency, exhibiting tens or hundreds of resonance peaks over the desired band of frequencies. It is believed that this high degree of structure is primarily due to the impedance resonances which are accounted for by the mismatch factor. Determining this factor is relatively straightforward. In contrast, it is believed that G(f) is usually slowly varying with f; if so, this would considerably reduce the measurement and data storage/management/processing demands. Other reductions are possible by spatially undersampling the near field measurements, and still satisfy a 3-6dB accuracy requirement.

Feasibility of the technique is being done in a microwave anechoic chamber in the 1-18 GHz range using generic test objects and 1:10 10 scale models of aircraft. Once feasibility has been demonstrated in this environment, the technique can be used to give guidance to the design of full scale simulators at lower frequencies.

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*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.

COMPARISON BETWEEN CALCULATED AND MEASURED FORWARD AND REVERSE CURRENT-VOLTAGE CHARACTERISTICS OF SEMICONDUCTOR JUNCTIONS

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We report an investigation to better understand the physical processes involved in second breakdown in semiconductor junctions. Experimental data of device damage and theoretical results from computer simulations are compared. The objective is to relate the failure threshold of a device to the physical parameters of the junction. By accomplishing this, one would be able to design and manufacture devices which are less susceptible to burnout. Also, a method for screening out the more susceptible devices is examined. With the aid of the forward characteristics, one can determine diode area and thickness, which can be used to calculate reverse bias second breakdown, a precursor to burnout.

LESSONS LEARNED FROM MAJOR SYSTEM BLACK BOX ANALYSES

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During the past three years, BDM has conducted interface circuit analyses on over 1,500 black boxes consisting of over 40,000 circuits and 300,000 components. This analysis is the combined effort of four large system assessments that are currently in the field or undergoing full scale development. In addition, the boxes analyzed represent a broad spectrum of technologies and design eras and include both commercial and military equipment. The results of these analyses efforts have been formatted and stored using IBM/PC data base systems. This massive data base has afforded the opportunity to evaluate the analytical results and draw broad conclusions which can be applied to evaluating the magnitude of system S/V hardness requirements. For example, if a new system is to be procured an evaluation of this data could be a factor in evaluating the scope of the hardening effort in terms of engineering dollars, time and complexity.

EFFECT OF VARIATION IN COMPONENT DAMAGE CONSTANTS ON EMP CIRCUIT THRESHOLD DISTRIBUTIONS

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Previous works have dealt with statistical distributions to examine the effects of various device model parameters on electronic component thresholds. Now that large data bases of thresholds of circuit interfaces are available, the effects of variations in component models on circuit thresholds can be examined. For example, the results of these studies can indicate the relationship between component damage constants and circuit threshold distributions. Conclusions can be drawn about the statistical importance of the damage models or intervening circuitry between the circuit interface and component modeled.

ABSTRACT

AN HYPOTHESIS ON EMP FAILURE THRESHOLD
TEST DATA (EMPIRICAL) DISTRIBUTIONS

R. MASON, IRT CORP.
H. DAVIS, JAYCOR

The graphical analysis of EMP threshold data clearly demonstrates the lack of symmetric distributions. Therefore, a question arises as to why, given the standard Wunsch Bell thermal damage model, one would expect assymmetric data since the physics would lead to a symmetrically oriented conclusion, i.e., the likelihood of a device failing from thermal failure would be equally likely at slightly above or below a mean or median value. The answer to this question is difficult since post mortem analysis of the actual device damage is rarely performed.

The authors present a set of computer analyses addressing the possbility of mixture models. Mixed models are the distributions resulting from the existence of multiple mechanisms (failures) in the data. It is demonstrated that a logical reason may exist for the empirical distributions observed. The outline of experimental procedures to remedy this problem are discussed in light of other research in the field.

ABSTRACT

AN APPLICATION OF ROBUST AND EXPLORATORY DATA ANALYSIS TO EMP COMPONENT FAILURE DATA

R. MASON, IRT CORP.
H. DAVIS, JAYCOR

Previous analyses of EMP threshold data have relied on using classical, elementary statistical techniques. These techniques typically include estimates of the population mean and standard deviation using x-bar and s-squared, evaluating chi-squared statistics, and then interpreting these results to fit the failure physics. An examination of these analyses shows that many times the data samples clearly do not exhibit the characteristics of a single "superpopulation". Additionally, when the data is compared to analytical models, substantive differences exist.

In order to alleviate these difficulties, modern statistical are applied to the failure data. These techniques, developed over the last ten years, provide resistance against extreme data values in the estimation of distributional parameters for nonstandard distributions. These techniques also place a heavy emphasis on graphical data interpretation when trying to "get a handle " on the underlying physical mechanisms generating the data.

Exploratory analysis techniques are similar to outlier type analyses in trying to understand extreme data observations. These robust and resistant statistical techniques were designed to estimate parameters in data with potentially extreme values which skew(and thus obscure the interpretation) parameter estimates obtained via the classical techniques.

The authors have also treated the results obtained from the various analysis models as a separate data set, i.e., equal weight with the laboratory results. Interpretation of the results of the analyses are presented in terms of the Wunsch Bell damage model and device physics.

Microwave and DC Pulse Failure Modeling

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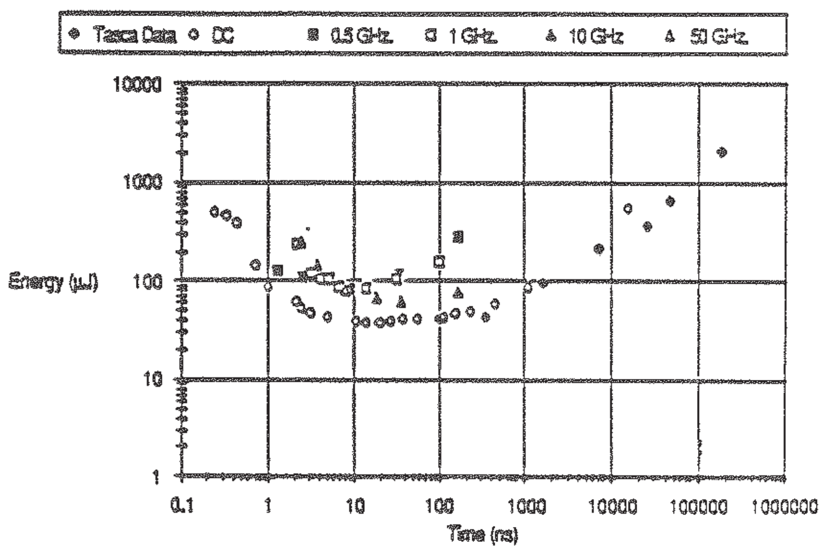
Using the one-dimensional, solid state device model BURN42, we have modeled the operation and failure of a 1N4148 diode during the application of high voltage microwave and DC pulses. We have performed some parameter studies using this diode as a base model and varyed several of the device parameters. The modeling results compare well with experimental results, and give some interesting insight into the operation and failure of a device in the short pulse regime. The following figure shows some of the results for the unmodified 1N4148 diode.



Note that in the sub-nanosecond regime, the failure energy increases, rather than remaining constant as current analytical theory indicates. The cause of this increase is due to heating in the substrate at the same time as heating in the junction region is taking place. Previous models (numerical and analytical) have neglected the substrate and concentrated exclusively on the junction region. When the applied pulse has a high enough voltage, then the resistivity of the substrate can cause heating comparable to that in the junction region, requiring more energy to be deposited in the device before a failure temperature is reached. Microwave frequency data is also shown on this figure, and has the same general shape as the DC curve, but is at a higher level. Note also that the microwave curves cross around 10 ns. Two-dimensional results in the short pulse regime indicate that current channeling and filament formation can change the short pulse results. We will also discuss some two-diemnsional results.

Work performed under the auspices of te U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48, and funded by The Defense Nuclear Agency, IACRO 86-837.

Microwave and DC Pulse Experimental Data for the 1N4148 Diode

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The 1N4148 diode is a commonly used Silicon switching diode. The amount of energy required to burnout out this diode is a function of the pulse width as well as the frequency of the applied high voltage burnout pulse. This particular diode was characterized previously by Tasca with DC pulses greater than 300 Ns in width. In this paper data will be presented on the burnout energy of the 1N4148 diode for DC pulses between 1 and 300 Ns. In addition burnout data for the diode at S (2.85 Ghz) and X (8.1Ghz) band will also be presented.

Work performed under the auspices of te U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48, and funded by The Defense Nuclear Agency, IACRO 86-837.

MILSTAR I/O Parts
EMP Damage Test Results

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ABSTRACT

Several types of digital I/O devices were tested to damage using simulated EMP pulses. Care was taken to properly stress the parts pin-to-chassis, as in EMP pin specs and in the eventual box pin-injection tests. Variables in the pin-to-chassis connection in the fixture were evaluated for their effect on the component failure mode and threshold. The effect of current-limiting resistance was also evaluated. Finally, when the test fixture and circuit were chosen, statistically significant samples of each I/O part were tested and de-capped to identify exact failure modes in the chips, e.g. junction burn-out, substrate diode voltage breakdown, etc. The failure thresholds were then characterized statistically and sure-safe and sure-kill limits established. The data was used to determine MILSTAR EMP pin hardening parameters and safety margins.

Work supported under USAF Contract No. F19628-85-C-0004.

DEVELOPMENT OF A TWO DIMENSIONAL GLANC CODE*

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One dimensional GLANC type retarded time codes[1] have proven useful in predicting the normal electric fields and the tangential electric and magnetic fields in a ionization radiation environment. It appears to be worthwhile to extend the technique to 2 dimensional plus retarded time so that the response of a collection of wires over a ground plane can be examined with reasonably fine gridding in the YZ plane. This would allow all six field components to be predicted.

In order to demonstrate the feasibility of a 2D GLANC Code Maxwell's equations ($H = B/Z_0$)

$$\frac{1}{c} \frac{\partial \bar{B}}{\partial t} = - \bar{\nabla} \times \bar{E}$$

$$\frac{1}{c} \frac{\partial \bar{E}}{\partial t} = \bar{\nabla} \times \bar{B} - Z_0 \sigma \bar{E} - Z_0 \bar{J}$$

were finite differenced on a two dimension (yz) plus retarded time ($\tau = ct - x$) coordinate system. This resulted in the system of equations

$$\gamma EX^{n+1}_{j,k} - \delta \left(EX^{n+1}_{j+1,k} + EX^{n+1}_{j-1,k} + EX^{n+1}_{j,k+1} + EX^{n+1}_{j,k-1} \right) = S_{j,k}$$

for EX plus 4 auxiliary equation for EY, EZ, BY, BZ. Various approaches to solving these equations including iteration and sparse matrix techniques will be discussed and the algorithm will be demonstrated for a simple coaxial geometry. The applicability to particle pushing simulations will be discussed.

REFERENCE

1. Longley H.J. and Longmire, C.L., "Development of the GLANC EMP Code", DNA 3221T December 10, 1973.

*Work partially supported by the Defense Nuclear Agency under Contract DNA001-85-C-0019.

URSI FACTUAL STATEMENT ON NUCLEAR ELECTROMAGNETIC PULSE (EMP) AND ASSOCIATED EFFECTS

This Statement was prepared by a Committee chaired by Mr. Manuel Wik, and consisting, in addition, of Dr. W. Ross Stone (Secretary), Prof. D. T. Gjessing, Dr. F. Lefeuvre, Mr. P.O. Lundbom, Prof. V. Migulin, Prof. S. Schwartz and Prof. F.L. Stumpers. Mr. Wik's address is:

FMV, Electronics Directorate
S - 115 88 Stockholm, Sweden.

PREFACE AND ACKNOWLEDGMENTS

This factual statement on nuclear EMP and associated effects was prepared by URSI (International Union of Radio Science) during the URSI XXI General Assembly in Florence, August 1984. The Statement was requested by SCOPE - ENUWAR (Scientific Committee on Problems of the Environment - Environmental Consequences of Nuclear War) within ICSU (International Council of Scientific Unions) and should be unemotional, non political, authoritative and readily understandable.

The Statement was unanimously approved (in principle) by the URSI Council meeting on 6 September 1984.

CONCLUSIONS

Nuclear EMP is one of the effects of nuclear weapons. The awareness of the high altitude EMP threat in different scenarios and the protection problems should be widely spread and taken seriously. This brief document touches only on a small portion of the known effects of EMP and associated effects. It is intended to make workers outside this field aware of:

1) The existence of nuclear EMP phenomena.

2) The fact that high altitude EMP effects can occur even though other nuclear effects such as shock, heat, and radioactive fallout are not present at ground level.

3) The fact that these effects can cover the whole area of the earth, that can be viewed from the burst location, e.g. a country or even a continent.

4) The potentially serious nature of the effects of high altitude bursts to telecommunications and power systems.

5) That in consequence, the possible disruption of communication grids could have a major significance for the development of a nuclear exchange.

6) That the possible disruption of power grids in large areas could cause chaos and lead to the collapse of the infrastructure of modern society if outages were to last for a longer time.

7) The various serious effects on satellite communications.

8) The techniques for protection against EMP and associated effects.

9) The necessity for valid testing and assessments of system performance in EMP environment.

It is hoped that the information presented in this statement and its scientific basis will emphasize the need to recognize the seriousness of nuclear EMP and associated effects.

AIRCRAFT ALERTING COMMUNICATION EMP (AACE)
UPGRADE HARDNESS SURVEILLANCE

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This presentation will discuss the electrical test techniques used for HS on the AACE upgrade. The AACE shielding enclosure consist of four elements: a shield room, a signal and power line conduit, an operator console and a remote klaxon sounding unit. The shielding topology attenuation must be maintained throughout the life-cycle of each AACE upgrade unit. HS testing detects and locates shielding degradations. Included in this testing are terminal protection devices which control signal and power line penetrations. The testing of the enclosure uses a two antenna free field attenuation technique; a triaxial transmission line for the conduits; and a hybrid antenna-sensor plate technique for surveilling the shield room and operator console floors. Time domain (pulse) transient absorber and continuous wave (CW) filter test techniques are also presented. Built in design features such as reference apertures, sensor plates, signal port chassis, signal line feed-throughs, antennas and transmission lines will be discussed.

IN-THE-FIELD HARDNESS SURVEILLANCE TEST TECHNIQUES AND RESULTS

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Using a variety of test techniques, on a deployed system in-the-field hardness surveillance measurements and maintenance were performed. The test techniques were:

1 - Single Wire Transmission Line
2 - Radiated Field Attenuation
3 - Four Point Probe
4 - 100kHz Direct Drive

Degradations of the shielding topology were determined, using each of the techniques, and simple maintenance improved the electromagnetic attenuation of the topology. The purpose of this presentation is to illustrate that these techniques are relatively simply to implement and yet they were effective for detecting and locating faults.

This presentation will discuss the four techniques, discuss limitations of each technique and show results obtained from surveillance performed on a fielded EMP-HARD system.

TACAMO Surveillance Program Results

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The TACAMO Hardness Maintenance/Hardness Surveillance (HM/HS) Program is a vital part of the TACAMO Hardness Assurance Program. In the TACAMO Hardness Program eight EC-130 TACAMO Aircraft are retrofitted with EMP kits as part of the Scheduled Depot Level Maintenance (SDLM) cycle. Following the kit installation a System Acceptance Test (SAT) is conducted to verify correct kit installation. This test is followed by a Naval Assurance Test (NAT) to verify that selected test point measurements are below a prescribed level. Following completion of the NAT the aircraft are delivered to the fleet. SDLM's are scheduled in three year intervals.

A HM/HS Program has been initiated to track the degradation of the EMP hardness that might occur over the life of the aircraft. In the HM/HS Program two aircraft BuNo. 160608 and BuNo. 162313 have been selected for surveillance testing to measure degradation rate and identify kits that will not function for the length of time between SDLM cycles. Free field pulse measurements will be conducted in the TACAMO EMP Simulator (TES); Trailing Wire Antenna (TWA) direct injection tests and TG3001 filter tests will also be completed. In the HM/HS Program, it is planned to conduct surveillance tests during the first NAT, at mid SDLM cycle, before the following SDLM cycle, and following the SDLM cycle. Kit failure rates that are much less than the SDLM cycle are referred to the Hardness Reliability Improvement Program (HRIP) for redesign.

To date one surveillance test has been conducted on aircraft BuNo. 160608 in August 1985 at the TES facility. This paper will discuss test planning and the results of this test. Further surveillance tests on aircraft BuNo. 160608 will occur in January 1987 (Mid-SDLM), July 1988 (Pre-SDLM), and January 1989 (Post-SDLM). The data from these tests and the test on the second surveillance aircraft BuNo. 162313 will allow the Navy to decide on the need for continuing the surveillance testing program.

Abstract

Pulse Sniffer System - A Way to Detect Hardening Degradations

by

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The military is fielding systems designed to survive HEMP radiation. Certain military aircraft depend on pressure hull hardening to provide shielding from potentially damaging transient fields. Shielded enclosures have been built for other systems. However, the effectiveness of shielding around apertures such as doors and windows can degrade with time. Surfaces oxidize, gaskets warp and materials corrode. A method is needed to detect, locate and measure degradations in a system's shielding. The Pulse Sniffer system was developed to meet this need. This paper summarizes the original development tests conducted on an unhardened C-130 aircraft and a screen room. It discusses the design modifications required to provide a system capable of detecting, locating, and measuring the dimensions of small degradations around aircraft apertures. The paper then goes on to describe later evaluation tests conducted on the C-130 aircraft and a MITRE screen room to verify the system's ability to detect, locate and measure aperture shielding degradations. Finally, this paper concludes that the system is useful and should be demonstrated on a hull hardened aircraft with the intent of someday being fielded by the government as an EMP hardness surveillance test method.

This work was sponsored by the Electronic Systems Division of the U.S. Air Force Systems Command.

DEVELOPMENT OF A CABLE SHIELD TESTER FOR IN-SITU HARDNESS SURVEILLANCE OF AIRCRAFT CABLES

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Abstract

This paper gives a status report on the development of a shielded cable tester. The tester measures the transfer impedance of shielded cables while they are installed on an aircraft. Design parameters and specifications for the tester were developed based on real technical and logistical issues for hardness surveillance of operational aircraft. Key design issues will be discussed along with the constraints imposed by making the measurements onboard an aircraft.

Data on the transfer impedance of actual aircraft cables with and without shield degradations will be presented. Most of this data was taken under laboratory conditions. However, preliminary data taken on an operational aircraft will be discussed.

PROPOSED DIRECT DRIVE TECHNIQUE FOR AIRCRAFT HARDNESS SURVEILLANCE

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The conceptual design of a relatively simple direct drive technique for injecting current on the outside of an aircraft has been completed. This technique could be used in both the high power pulse or low power continuous wave (C. W.) modes as an EMP hardness assessment and/or surveillance tool.

The objective of this effort was to develop a technique that could be used to directly drive continuous wave (C. W.) or high power pulse currents onto the skin of an aircraft for EMP hardness assessment and/or surveillance. The chosen approach was to make the aircraft the center conductor of a pair of crossed transmission lines. Since the wing and the fuselage could be fed independently, they could be fed in phase or out of phase with either C. W. signals or a fast rise time pulse. The goal of this technique is to produce appropriate skin currents (in the time and/or frequency domains) on the surface of the airplane. This enables the measurement of the transfer function between the skin current and the pin or cable currents. It is this transfer function that can change during the life of the system. This technique has been discussed in the past and is sometimes known as the skin current injection technique (SCIT). This technique has been rejected by some because they had difficulty interpreting the results. However, the present study as well as the recent development of direct drive techniques for missiles, have shown that the technique should give good results if it is used intelligently in frequency ranges where multiple reflections are not significant. This is generally true at the aircrafts fundamental and 3rd harmonic. An aircraft technique should be as broad band as possible (reasonably flat response up to at least the aircraft's 3rd harmonic) and be capable of injecting enough C. W. current to have at least an 80 dB dynamic range between the aircraft and cable currents and/or produce threat level A/C currents in pulse mode. In addition the technique should provide good ingress and egress for the A/C and should be useful for a range of A/C.

This study showed that a simple test fixture consisting of a small number of wires above the A/C plus some conducting spacers below the aircraft, would make the A/C into a 10 to 50 Ohm transmission line. This impedance is high enough so that the test fixture does not need to be precise and low enough so that the pulser voltages are not excessive to get a few kA. The high frequency/fast rise time currents spread out over the entire A/C surface. The simple test fixture provides easy ingress/egress and adapts to a variety of A/C. Terminating the transmission lines reduces standing waves, improves the high frequency response and facilitates analysis. One of the major advantages that this technique has for hardness surveillance is that it concentrates the current on the surface of the aircraft rather than radiating the energy into space and the use of C. W. means that the signal has high spectral power densities at the high frequencies where the hardness degradations are most significant.

AIRCRAFT ALERTING COMMUNICATIONS EMP
(AACE) UPGRADE HARDNESS MAINTENANCE (HM)

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This presentation will discuss the HM program used for the AACE Upgrade. The AACE HM program has three elements for ensuring a life-cycle EMP-HARD system. These elements are: hardness critical item (HCI) labeling; hardness surveillance (HS), both inspections and testing; and hardness critical processes (HCP) task analysis. HCI labeling on hardware, technical orders, drawing and other documentation is essential for appropriately maintaining, replacing or stating procedures involving HCIs. HS inspections are a "first-line-of defense" for monitoring the shielding integrity of the system toplogy. HS inspections provides a qualitative statement. HS testing requires electrical instrumentation for obtaining measurements which makes a quantitative statement about the shielding attenuation of the system topology (it monitors the EMP allocations). The HS testing for AACE is 100%, i.e. testing all seams, apertures, feed-throughs and terminal protection devices. HCPs are all operational and maintenance procedures which rendered the AACE upgrade facility vulnerable to EMP. How these HCPs interface with the Logistic Support Analysis and other logistic requirements will be discussed.

NUCLEAR SURVIVABILITY (HARDNESS) ASSURANCE, MAINTENANCE AND SURVEILLANCE (HAMS)

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Understanding how production assurance and deployment maintenance, of a nuclear survivable system, relates to surveillance is discussed in this presentation. The relationships between assurance, maintenance and surveillance is explained from an understanding of the electromagnetic penetration mechanisms and hardening design elements. From this point of view surveillance is a tool, involving electrical testing and visual/mechanical inspections. Electromagnetic (EM) attenuation ratios are discussed along with relating various EM quantities to each other. A number of different electrical test techniques are described including shielding enclosure and terminal protection device testing. Testing techniques are divided into three categories; direct attenuation circuit parameter verification and base line data monitoring. The electrical measurements obtained from any one test category is either an intrinsic, extrinsic or a radiated field datum. Finally, rationale for designing faults into a system is discussed.

TITLE: Portable EMP Test Set For Hardness Assuredness and Maintenance Testing

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ESSENCE:

There is increasing evidence that EMP protection devices can be degraded by lightning or manmade EMI without being detected on the system they protect.

DISCUSSION:

Soft degradation of zeners, MOV's, gas tubes, Pi filter networks etc. can leave EMP hardened equipment vulnerable to the next lightning strike or an EMP incident. Joslyn Defense Systems, Inc. has collected field test data that illustrates EMP protection devices do degrade but become difficult to detect using available test equipment. Further, testing of these devices with conventional test equipment may not provide a true indication of degradation when compared to an EMP (hi frequency) threat. However, observations in the field indicate that a cost effective EMP Hardness Assuredness and Maintenance program is possible using EMP threat waveforms at the pin level.

RESULTS:

Joslyn Defense Systems, Inc. has developed a portable, Go/No-Go EMP pin drive tester that can be taken into the field for on board aircraft, ground shelters or shipboard testing. The test set detects degradation of EMP terminal protection devices at the pin level caused by lightning, manmade EMI or improper installation after a maintenance action. In this manner, an effective Hardness Assuredness and Maintenace program can be implemented without the costly dismantling of EMP protected equipment.

Shield Room HAMS (Hardness Assurance Monitoring System)

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There is a growing number of EMP hardened communications systems in the DOD inventory. The need for hardness assurance, maintenance, and surveillance test equipment and techniques for these EMP hardened communications systems has been recognized. A Shield Room HAMS (Hardness Assurance Monitoring System) has been developed to perform in-situ tests of components of the EMP shield for a typical bolted seam, double-wall shield room with signal line, power line, RF line, and fiber optic penetrations. A description of this discrete frequency CW Shield Room HAMS will be presented. Also discussed will be (1) the results of experiments to determine the greatest number of filters which can be grouped together for transfer function measurements and still maintain the ability to detect a degradation in one filter, and (2) a description of an in-situ test for power line spark gaps that is transparent to both the shield room's systems and the commercial power system.

Shielded multiconductor cable coupling phênomena

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ABSTRACT :

Overhead multiconductor screened cables are used in the distribution part of the local french telephone network. Having noted several anomalies due to EM interference caused by broadcast radio transmitters, we conducted an investigation into coupling phenomena in shielded multiconductor cables.

When a multiconductor cable is illuminated by an incident EM field the problem is to find the internal disturbing voltage and current on anyone conductor. It is known that there are two interaction problems : one external and one internal. External interaction has been studied by many authors [1] and leads to the calculation of the current and voltage distribution on the shield. I shall therefore focus my presentation on the internal interaction.

An experimental method to determine the inductance and the capacitance matrices was proposed by AGRAWALL et al. [2]. We applied it to the case of the shielded cable and developed an automatic wide band frequency system using a switching matrix. This paper presents the theoretical method which leads to the experimental study, describes the automatic set up and shows the obtained results The frequency band for which this method is valid is discussed. Using the measured parameters and the transfer impedance of the shield we give the calculated response of a one pair shielded cable illuminated par a plane wave EM field. Finally we give the measured response obtained in a parallel plate simulator and discuss the results.

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IEEE Trans. EMC, Vol. EMC21, Feb. 1979

MEASURED CROSSTALK OF MULTICONDUCTOR CABLES THAT USE A SINGLE CONNECTION TO THE REFERENCE PLANE

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Crosstalk within a cable bundle is one mechanism by which electromagnetic energy can be coupled from the exterior surface of a system to the pins of a critical line replaceable unit (LRU) since a cable bundle may include both relatively high amplitude noisy signals and relatively clean signal lines for critical circuits. Consequently an understanding of crosstalk coupling is important for understanding EMP coupling to LRU pins.

A common specification for aerospace systems is to require the circuit return be carried with the circuit high side (preferably as a twisted pair) and the circuit to be connected to the reference plane at no more than one point. The purpose of this requirement is to reduce coupling of interference through common impedance coupling. The purpose of this investigation was to measure the voltage crosstalk of a variety of shielded multiconductor cable configurations and to compare the results to the cable coupling model published by Paul.

The voltage response crosstalk in an 8 pair multiconductor cable was measured for three cable lengths (1, 3, and 10 meters), two internal shielding configurations (unshielded and braid), and several termination conditions. The measurements covered the frequency range from 1 kHz to 200 MHz. All cables were constructed in such a way that each pair was connected to the overbraid that served as the reference plane at only one point. The measurements are consistent with the theory published by Paul, after the difference in cable configuration is taken into account.

HEMP COUPLING TO EXTENDED NETWORKS OF MULTICONDUCTOR CABLES*

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Simulation fidelity requirements for high altitude electromagnetic pulse (HEMP) excitation of extended Army systems need to be established for bulk current injection testing (CIT) techniques. The relationship between the bulk current and the individual pin currents for a variety of excitation processes is used as a measure of the simulation fidelity. Determining this relationship is complicated by the complexity and spatial extent (over 100s of feet) of Army systems. Large numbers of multiconductor cables with many branches and breakouts terminated with a variety of linear and non-linear load impedances further complicates the analysis. Current "accumulation" effects associated with HEMP coupling at grazing angles must be considered for the entire network to determine the bulk currents on "down stream" cables. The amplitude and phase requirements for multipoint bulk current injection techniques must reflect current accumulation effects.

The results of model calculations of the response of a typical Army system will be presented. These will include analysis of the system as a network and calculations of individual pin currents for several multiconductor cable configurations with a variety of termination impedances. These calculations have been performed using a series of analysis tools discussed in papers presented at the 1982 NEM Conference.[1,2] The foundation of this approach rests on the ability to calculate the distribution of Norton and Thevenin equivalent source terms for arbitrary multiconductor cable configurations, including branching, for arbitrary excitations. When used with a multiconductor transmission line code the individual pin currents at interfaces can be determined. These calculations are used to develop and evaluate improved injection techniques for extended Army systems.

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*Work performed for Harry Diamond Laboratories under Contract Number DAAL02-85-C-0206.

EFFECT OF THE GROUNDING OF THE REFERENCE CONDUCTOR ON THE SHIELDING EFFECTIVENESS OF A MULTI-CONDUCTOR SHIELDED LINE

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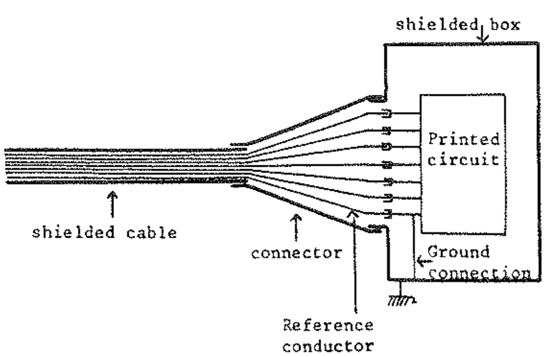
Multi-conductor transmission lines are usually made with signal-carrying conductors and a common or reference conductor to which the line voltages are referenced. Furthermore, to decrease the electromagnetic coupling of these wires to an incident electromagnetic wave, a shield is put above all these conductors. Practically the configuration at the end of the line is represented in the Figure below. The shield of the cable is connected to the shielded box of any electronic equipment through the sheath of a connector. The reference conductor may be connected or not to the grounded box.

If the connections between the shield of the cable, the connector and the box are perfect, the disturbing current flows without discontinuity along the outer sheaths and the shielding effectiveness depends on the transfer parameters of each component. However, if there is a fault in the connection between the shield and the connector, a part of the disturbing current can be shunted by the reference conductor and thus the disturbing voltages appearing at the input of the electronic equipment are strongly modified.

In this paper, we present experimental results which have been carried on short cables (1 m long) both in frequency and time domain with a spectrum ranging from few kHz to about 30 MHz. We show how the amplitude of the disturbing voltages depends on the connection of the reference conductor to the ground. These results are then extrapolated to long cables.



WIRE-TO-BULK CURRENT MEASUREMENTS ON A MULTICONDUCTOR CABLE

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CW and pulse measurements were performed at the Air Force Weapons Laboratory on a shielded multiconductor cable to investigate the relationship between single wire currents, Iw, and the bulk cable current, Ib. This Iw/Ib relationship is very important for system-level EMP testing where it is impractical to measure each and every single wire current. The three basic objectives of these measurements were: (1) increase the data base of bulk-to-wire current relationships, (2) verify and/or modify existing theories relating bulk-to-wire currents, and (3) establish test techniques involving table bundle currents.

Even though a definitive Iw/Ib upper bound has not been established, time domain data obtained in previous system-level tests have suggested an Iw/Ib upper bound in the range from 2 to 5. Our CW results indicate that the single wire current is less than the bulk current at frequencies below 10MHz, regardless of the load terminations employed. At frequencies above 50MHz, large Iw/Ib ratios (> 10x) were found to occur for a relatively small fraction of the loaas tested. For these particular load terminations we observed phase cancellation among individual wire currents which produced a small bulk vector sum, and therefore, a large Iw/Ib ratio (> 20). These results are tempered by the observation that the large wire-to-bulk ratios were achievable only over a narrow frequency band.

AN ALGORITHM FOR OBTAINING EMP-INDUCED TRANSIENTS IN BURIED CABLES

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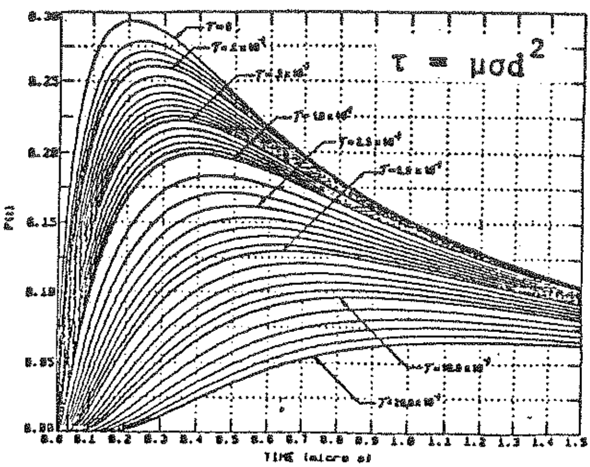
ABSTRACT

Hardening the nation's electronic equipment against threatening EMP transients is an astronomical task. It will require the services of people who have no background in the sophisticated mathematics found in the theoritical description of EMP problems. Thus, solution techniques that provide rough, but easy to determine, estimates of threatening EMP transient levels will be very valuable. The algorithm for buried cables described in this paper addresses this need.

The time waveform of currents induced by EMP in buried cables is determined numerically using a Fast Fourier Transform algorithm. These numerical results are displayed graphically (figure) as a function of the electromagnetic properties of the ground and the distance of the cable below the surface. The solution is obtained by a procedure using these graphs and simple calculations.



*Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under Contract No. DE-AC05-84OR21400.

ANALYSIS OF ELECTROMAGNETIC PULSE COUPLING TO SQUIBS

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Abstract

Modern electronic systems may face the Electromagnetic Pulse (EMP) threat originating from high altitude nuclear burst. The EM pulse having amplitude of several thousand kilo volts/meter (E-field) and nano seconds rise time will couple to Electro-explosive devices (EEDs) used in weapon systems through connecting leads and cause premature weapon detonation and create a mission failure.

In this paper, an attempt is made to compute the EMP energy coupled to squibs through the interconnecting wires. In our analysis the external connecting wire pair to EEDs is modelled as a pickup dipole antenna and the wire inside the pod is modelled as a transmission line. Double exponential EMP waveform model coupled to dipole antenna is first sampled at 4 nsec interval and from the collection of 512 samples, discrete fourier transform is computed. The coupled voltage to the squib bridge wire is calculated at these discrete frequency intervals and then the time domain waveform is computed. Hence, the maximum coupled power is computed, taking the peak amplitude of the waveform into account. To reduce the coupled EMP energy to a safe level, several mitigation techniques, such as, the use of low-pass pin-filter, lossy line filter, twisted wire pairs are considered theoretically and optimum remedial measures to protect the EED's from EMP threat are suggested.

To validate the model, the impulse sensitivity of the squib is measured experimentally as follows. A thermistor sensor is connected in the feed-back path of a timer circuit connected as an oscillator. The rise in temperature in the thermistor is calibrated against change in frequency of the oscillator. From the known source of a transient generator, the transient voltage is fed directly to the squib. Amplitude and the repetition rates of the transient waveform is changed keeping the thermistor in contact with squib bridge wire and the change in frequency of oscillator is found. Experimental results are plotted in graphical forms. Assuming a linearity between simulated transient pulses to the EMP waveform the rise in temperature of squib is interpolated from practical results. From our analysis, it is observed that for the protection of squibs, the use of lossy line filters in wire interconnects are preferable. The external wire lead length to squibs should be as small as possible and the wire pair should be invariably twisted wire.

STATISTICS FOR ELECTROMAGNETIC PULSE ANALYSES

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The electromagnetic pulse (EMP) assessment and hardening technology is highly complex. This complexity is most often accommodated by considering mainly the worst-case conditions of the various parameters of uncertainty. This approach has led to most assessments being more severe than might be justified and hardening recommendations that may not be essential for reasonable assurance of hardness. Many theoretical and experimental programs have been carried out that yield only this worst-case form of guidance. Worst case is acceptable if the worst case indicates no vulnerability. But when worst-case vulnerability is found, the system should be considered for further analysis rather than hardened without it.

In the National Research Council 1984 study, "Evaluation of Methodologies for Estimating Vulnerability to Electromagnetic Pulse," considerable criticism was leveled at the EMP community for its lack of use of statistics. The High Power Microwave (HPM) Hardening Technology Program was directed to make proper use of statistics in deriving all assessment and hardening technology. (This was described at the Nuclear EMP Meeting (NEM), 1984.) Our experience has shown that a broader knowledge of the applicable statistics is needed by the working engineers in order to carry out this requirement most completely. The design of every theoretical and experimental task is influenced by considerations of obtaining significant distributional information.

A search was carried out to find a textbook most suitable for a formal course in statistics as applied to the assessment and hardening of systems to EMP and HPM. An instructor was selected who agreed to be responsive to the applications problems to be brought up by the students. The resulting curriculum is heavily biased toward "classical" statistics (Frequentists), with only a brief introduction to Baysian statistics.

We will discuss the contents of the course. It used the text, "Statistical Models for Engineering," by Gerald J. Hahn and Samuel S. Shapiro. Topics include statistical distributions, transformation of variables, student's t, and system examples as brought in by the students. No text was available that addressed the required topics with the most helpful illustrations. It is hopes that this paper will encourage others to write a text filling this need or to create a curriculum that may be available nationwide.

VARIATIONAL STUDY OF BOX HARDENING ASSESSMENT

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A variational study is made of three assumptions prevalent in analyses predicting the "Probability of Survival" of a single pin form an EMP event. The three assumptions studied are: the effect of estimating component threshold parameters from a small sample of components, the effect of assuming a single mode failure for the component, and finally the effect of the log-normal distributional assumption for stress and threshold. The study uses several tolerance intervals and Monte Carlo simulation to study the effect of estimating the threshold parameters. Further, the bootstrap method is used with measured aircraft pin stresses and transistor failure thresholds to study the effects of multi-modal failure and the log-normal distributional assumptions. In all cases, reliability/confidence curves are presented.

Submicrosecond Structure of Lightning Return Stroke Fields

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Abstract

An experiment to measure the electric field, E, dE/dt, and HF signatures that are radiated by lightning return strokes at known locations was conducted at the NASA Kennedy Space Center during the summer of 1984. Values of the maximum dE/dt during the initial, fast-rising portion of first strokes were found to have a mean and standard deviation of 45.4 ± 13.4 V/m/μsec, when range-normalized to 100 km, when HF at 5 MHz was used as the trigger signal. The full width at half-maximum of dE/dt was 97 ± 18 nsec. If these fields are produced by a single current pulse that propagates up a single channel at a typical velocity of 10^8 m/sec, then the above values of dE/dt imply that the mean maximum dI/dt at the lightning source is about 230 kA/μsec, a value that is substantially larger than most tower measurements.

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A COMPARISON OF CALCULATED AND MEASURED VALUES OF THE OPTICAL RADIANCE OF A LIGHTNING CHANNEL

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Computer calculations of the brightness of a lightning channel are compared to measured values. The computer code includes: a one-dimensional finite-difference hydrodynamics algorithm; Joule heating; a tabular equation of state for air; and a multigroup radiative transport treatment. The radiative transport was calculated in the diffusion approximation, and one of the frequency groups corresponded to the .45 to 1.07 μ wavelength range, the range of sensitivity of the photodetector. The measured values of the current as a function of time were input to the code and the light radiated by the channel as a function of time was calculated.

The calculated values of the radiance are compared with the radiance of three lightning channels that was measured at South Baldy Peak near the Langmuir Laboratory of the New Mexico Institute of Mining and Technology. The light output from a short length of a lightning channel was measured at the same time that the current into the ground and the electromagnetic fields at a distance of about 50 m from the stroke were recorded. The lightning, which was triggered by rockets, struck an aluminum mast that extended 20 m above the ground.

LIGHTNING MODELING: BREAKDOWN, CHARGE, AND CHARGE DENSITY

by

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The lightning discharge is a transient phenomena strongly dependent upon initial conditions at the time of return stroke initiation. Theoretically, the charge distribution in the vicinity of the discharge is sufficient to determine the necessary initial conditions. It is convenient to examine this distribution in two parts: a) the charge distribution in the cloud due to the charge separation process(es) and b) the redistribution that occurs during the step-leader process. Because incorrect assumptions about the original charge/breakdown/charge density relationships can lead to erroronous results in the redistribution/leader process, this research focuses on the former. Assumptions are discussed and data generated to obtain a single set of universal curves which permit the user to find over a wide range the interrelationships between the charge density, the maximum effective breakdown field intensity and the maximum transferrable charge for heights of the dipole's lower charge center between three and eight kilometers. Example uses and physical consequences of the interrelationships are discussed.

FUNDAMENTAL INVESTIGATIONS OF TNS APPLICATION FOR CALCULATION OF LIGHTNING-INDUCED VOLTAGES

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1.Introduction

Generally lightning-induced voltage for multi conductors system is shown by equations as follows.

$-\delta V/\delta x = L\ \delta I/\delta t$

$-\delta I/\delta x = C1\ \delta/\delta t(V-Vin) + C2\ \delta/\delta t\ (Vin-Vim)$

where, V is a propagation voltage over line, L inductance matrix, I current, Vin, Vim inducing scalar potentials, C1, C2 matrix by capacitance. The term C2*(Vin-Vim) is for the induced voltages between multi conductors. Calculated results of lightning-induced by digital computation are already reported by Yokoyama(1) and Yamamoto(2) et al. In this paper, TNS(Transient Netwok Simulator) application which may be more useful for the statistical probability estimation of the insulation coordination of distribution network than digital computation is fundamentaly investigated.

2.Circuit fundamentally investigated

In Fig.1, L,C are inductance and capacitance of distribution system, Rs,Rp,Cs and Cp are circuit elements for the generation of source lightning-induced voltage. Eo is charged voltage in capacitance Cp and lightning-induced source voltage Vi is generated by closing of switch Sw. For the maximum values of real part (r) and imaginary part (y) of the admittance between terminals A-A' as s function of frequncy, $r=C/Cp*n/(n+2)$ and $y=C/Cp*n$ (where $n=Rs/Rp$) must be negligibly smaller than 1.0.

3.Results

In Fig.2, voltage distribution along line is shown at main stroke of horizontal distance of 50m from #1. ○ shows results by digital computer and X by TNS. The value in node #3 is slightly differnt due to the not precisely controlled operation of switch of Sw in Fig.1. An analysis of the lightning-induced voltage in multi conductors of distribution system is performed for the estimation of effects of grounding resistances and lightning arresters.

4.References

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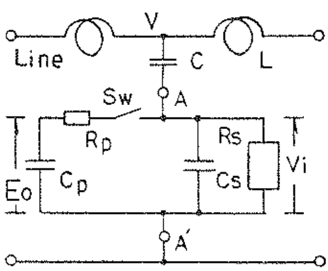

Fig.1 TNS Element Arrangement

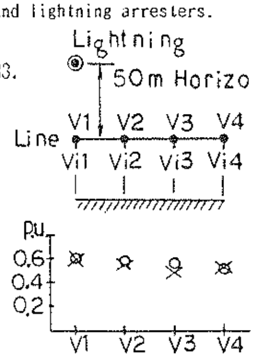

Fig.2 Analyzed Circuit and Result

CURRENT AND VOLTAGE INDUCED ON AN AERIAL TELECOMMUNICATION CABLE BY A LIGHTNING DISCHARGE

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At first, we present an efficent numerical code to determine the electromagnetic field radiated by a cloud to ground discharge. Since one of the main problem is the computation of the Sommerfeld integrals in frequency domain before applying Fast Fourier Transform procedures, we have compared the results given by the various approximations available in the literature to the exact solution of the Sommerfeld integrals. This comparison have been made for many positions of the transmitting vertical dipole and for various ranges between this dipole and the receiving point. This allows to choose the best approximation for a given configuration. By integrating the field produced by each element along the channel, the total radiated electric field is computed.

Then we consider the coupling to an aerial telecommunication line, 1 km long, situated at a height of 6 m and grounded at both ends. The coupling is calculated through the transmission line theory to avoid a too important time of computation.

A comparison between theoretical and experimental results of the current induced by a triggered lightning stroke is given together with a parametric study of the shape and amplitude of the current as a function of the relative position of the lightning discharge.

Lastly, the shield of the telecommunication cable being characterized by a transfer impedance, the surge voltage of the common mode is determined.

New Concept of the Termination of a Bounded Wave EMP Simulator.

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A terminator designed for all frequencies in the EMP spectrum will be presented with some experimental and numerical results.

The termination is under development for the new Swedish EMP simulator SAPIENS II.

The classical parallel plate simulator with conical sections at both ends was designed as a transmission line. The charachteristic impedance is kept constant along the line in order to guide the TEM-mode without reflections to the terminator for dissipation. A severe constraint, though, is the upper frequency limit which is given by the requirement that the height of the simulator should be much smaller than the actual wavelength. Higher frequencies will scatter from the bends in the top plate, thereby producing higher order modes which are not properly terminated. The best location for a working volume was found to be in the first conical section. This fact gave rise to another design of simulators consisting of the first conical section only, terminated by a set of wires with distributed resistors between the top plate and the ground. The resistors terminate the TEM wave, but again there will occur some scattering at the junction between the plate and the wires, as well as from the wires and the resistors.

Once the step is taken from the transmission line theory to a more general treatment of the scattering process in order to minimize the reflections from the terminator, the new concept becomes obvious. As in any broad-band non-reflective construction, the idea is to increase the scattering progressively along the termination.

The new terminator comprises two parts, one tapering section and one dissipative section with wires interconnecting distributed resistors. In order to decrease the scattering from the plate-wire junction, the tapering section is introduced consisting of triangular plates connecting the wires to the top plate. The resistance values are continuously increasing outwards along the wires which are projected horizontally from the junction and are gradually bent down to be connected to the ground plate.

DESIGN OF VARIABLE-HEIGHT LARGE WIRE NEMP-SIMULATOR ANTENNAS

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While in the case of small NEMP-simulators it is almost irrelevant whether the antenna is of fixed or of variable height, if very large NEMP-simulators are considered it is of considerable interest that the height of the simulator antenna can be varied in a significant range. From the one side, it is often necessary to analyse the effect of NEMP on very large objects (e.g., ships or aircrafts), even in simulated NEMP of smaller peak value than the standard, and on the other side it might be necessary to test smaller objects (e.g., containers, tanks, complete ground communication systems, etc.) in simulated NEMP of much larger peak value than the standard. A large NEMP-simulator with an antenna of variable height enables that these two tasks can be accomplished with a single simulator.

In designing a simulator with variable-height antenna, there is a number of problems which need to be solved in addition to those existing in the case when the antenna is of constant height. Two most important of these are, probably, the following: (1) finding a mechanical construction which enables simple and fast change of the antenna height, and (2) the electrical analysis of the effects of the variable antenna height, including such important topics as the necessary value of the pulse-generator voltage to obtain a desired field in the simulator or, conversely, the field which can be obtained in the simulator for different antenna heights corresponding to a given voltage of the pulse-generator. This is not a trivial analysis at all, and a number of approximations must be introduced in order to solve the problem.

This paper is aimed at presenting some results relating to mechanical and electrical design of variable-height large wire NEMP-simulator antennas.

OPTIMAL DESIGN OF OUTDOOR TEM WIRE NEMP-SIMULATOR ANTENNA

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When designing NEMP simulators, three basic requirements should be met concerning the simulator antenna: (1) it should be well matched to the pulse generator, (2) it should not have appreciable reflected wave from its far end, and (3) in the operating volume it should produce the field as close as possible to the standard NEMP. In order that these three conditions could simultaneously be met, it is convenient to design the simulator antenna by means of numerical optimization techniques. This paper is aimed at presenting a method for optimal design of TEM wire NEMP-simulator antennas, as well as experimental results obtained on a small-scale model of an optimal antenna.

Briefly, cylindrical part of the NEMP-simulator antenna is analysed using quasi-static approach, and the desired profile of its cross-section is obtained by optimization of a function of the characteristic impedance of the TEM line (which is determined by the resistance of the pulse generator) and of the homogeneity of the field in a desired operating volume. The quasi-conical ends of the antenna are then designed to be electrodynamically as similar as possible to the cylindrical antenna part at any cross-section perpendicular to the antenna axis. One of the ends is terminated by a resistor of resistance equal to the line characteristic impedance, and the other end is connected to the pulse generator.

A small-scale model of an optimal antenna was made and is properties measured. It was found that the input and, to a lesser extent, output terminals must be designed with great care in order to obtain the proper frequency response of the antenna. Once this had been done, the antenna properties were found to be quite close to the optimal: the impedance of the simulator antenna was found to be practically equal to the cylindrical antenna part characteristic impedance, and the homogeneity of the field approximately as predicted by the quasi-static model, in the whole range of frequencies of the standard NEMP.

NUMERICAL EVALUATION OF THE FIELD INSIDE AND OUTSIDE OF NEMP SIMULATOR WIRE ANTENNAS

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Pulse waveforms within the work space of an NEMP simulator can significantly differ from the generator waveform due to the radiation from the input part of the simulator, reflections and other problems associated with launching a TEM wave. When designing large NEMP simulators it is, therefore, necessary to check the waveforms at a number of points within the work space. A method for numerical evaluation of the field waveform within wire NEMP simulators is presented here. It is based on the two-potential equation in frequency domain and the point-matching method with polynomial approximation of current distribution /1/. However, due to a very large ratio between the pulse duration and its rise time, it is inconvenient to directly apply the fast Fourier transform (FFT). Instead, Green´s functions (i.e., fields due to an impulsive generator driving the simulator) are evaluated by using FFT, and these functions are then convolved with the true generator waveform to obtain the field within the simulator.

Large outdoor NEMP simulators can create a strong field in their vicinity, which can interfere with other equipment at the test site, or even further away. It is very useful to know this field before building a simulator. This field can be obtained by using the same technique as above. However, the field radiated from the simulator has the form of a relatively short pulse because higher frequency components are dominant in the field spectrum. Therefore, the waveforms can be obtained directly by using FFT.

The theoretical results were found to agree with predictions, waveforms available from existing simulators and frequency-domain measurements on a small-scale model.

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EM field measurements near a parallel plate simulator

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ABSTRACT :

In 1980 the CNET built the SIEM 80 kV parallel plate simulator, which is 50 m long, 1.5 m high and 1.5 m wide.

In order to test electronic telephone bays it is necessary to construct a large simulator of the same type with 400 KV capability.

As the new simulator is to be located near an airport and electronic laboratories, before selecting its site and orientation, it is necessary to measure the EM field surrounding the actuel SIEM 80 kV (both near the ground and airborne using a helicopter).

An optical system which gives the azimuthal and elevation angles is used. This paper describes the experiment, presents the radiated EM field in the time and frequency domains, analyses the results and compare them to those given an horizontal progressive wave antenna.

IMPROVEMENTS TO THE SEXCE COUPLING MODEL OF INTERIOR WIRE RESPONSES*

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The SEXCE coupling model of interior wire responses was first developed in two parts: a shielding effectiveness (SE) term that described the hull effect and a coupling effectiveness (CE) term that described an interior wire's antenna-like response to the penetrating field. This model predicts the current response on interior wires under a variety of real world conditions, and permits estimating the upper bound of current amplitudes vs frequency.

It was noted that the Q of wire resonances were sharpened when the wire was placed inside an enclosure. By characterizing the amount of sharpening, it was possible to extend the SEXCE model to where it characterized the energy of interior responses as well as their amplitude.

Two unambiguous features of the SEXCE model are the aperture cutoff frequency, below which the response falls off rapidly, typically on the order of ω^2, and the ω^{-1} antenna-like rolloff above the aperture cutoff frequency. The behavior below aperture cutoff, where shielding can be said to be effective, was not fully characterized. Asymptotic limits have been developed that more completely describe this regime. This allows "back of the envelope" estimates to be made in this regime of the shielding effectiveness. This complements our existing capability to make these estimates above the aperture cutoff frequency.

*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 funded by The Defense Nuclear Agency, IACRO 86-837.

Calculation of Rebar Attenuation and EMP Induced Transients Inside Rebar Enclosures

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In designing EMP-hardening of cables and electronics inside rebar enclosures the EMP-effects must be well known; important are the time dependant electromagnetic field and the transients of voltage and current induced on cables.

Experimental techniques may be used but besides their high cost and effort they may cause temporary reductions or even break-downs in power systems of the facility. Therefore computer programs to calculate the effects are often prefered.

In this paper a computer program is presented which can be used for various problems of shielding and coupling.

First of all the shielding effectiveness of single- or double-course rebar constructions is calculated in the frequency domain by using the geometric and electromagnetic parameters. Apertures such as doors or windows and different detector points whithin the building can be considered.
Then the Fourier-spectrum of a plane wave in the frequency domain (standard EMP or any simulation pulse) is multiplied by the given (calculated) shielding function to obtain the spectrum and waveform inside the building. This is the source of common-mode coupling to cables.
The transients of voltage and current on cables are computed in the frequency domain and then they are transformed to the time domain.
The cables may run horizontally or vertically. The polarization of the field, the parameters of the (lossy) cable and wall reflection coefficients can be considered as well as different types of cable shields and conductor configurations. The terminating impedances at both ends are optional (characteristic impedance, short/open circuit, etc.).

Different examples are presented to illustrate the computer program as a useful tool to calculate the EMP-effects, to figure out sensitive parameters, to prepare experimental techniques and to design the best EMP-hardening.

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This work was supported by the MINISTRY OF DEFENSE OF THE FEDERAL REPUBLIC OF GERMANY

THE USE OF TRANSMISSION-LINE MODELLING (TLM) IN INTERNAL INTERACTION PROBLEMS

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This contribution describes three different approaches to the problem using the TLM method (1) and compares results.

Assessment of internal interaction involves the calculation of induced currents in wires placed inside metallic or semi-insulating structures illuminated by electromagnetic fields.

The normal procedure is to calculate the surface currents on the structure due to the incident E.M. field and then to compute the induced currents on wires inside the structure using the appropriate coupling parameters (2). Alternatively, the E.M. field incident in the vicinity of the wire may be calculated and coupling represented by voltage and current sources on a one-dimensional circuit model of the wire. In one method of solution (3) the wave equations are formulated and solved in the frequency domain by standard numerical techniques.

In the first place this paper describes an alternative way of solving the one-dimensional circuit model in the time domain. Solution in the time domain offers advantages especially in the treatment of non-linearities. Secondly, a three-dimensional model of the field problem is developed by populating the space around the wire by a network of intersecting transmission lines. The wire itself is described, to any detail required, by short-circuiting appropriate nodes in the transmission line network.

Finally, since description of the wire in increasing detail requires a very fine mesh with obvious penalties in the use of computer resources, developments in diakoptics are also described. This give a more efficient use of computational resources.

Circumstances under which one approach is better than others are not necessarily obvious and this aspect of the work will be discussed.

Acknowledgement: This work has been carried out with the support of Procurement Executive, Ministry of Defence, U.K.

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ELECTROMAGNETIC FIELD DISTRIBUTION AND FREQUENCY RESPONSE FOR EMP EXCITATION OF AN S-280 EMP SHELTER

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ABSTRACT

The electromagnetic field response has been calculated for an S-280 shelter with both resistive and inductive door seam impedances in an NEMP environment. Peak field distributions were calculated throughout the shelter showing the greatest amplitude near the seams. The frequency response, calculated at various points throughout the shelter show a clear delineation between high frequency propagating modes and lower frequency evanescent modes. The propagating modes start with the lowest frequency near the fundamental resonance mode of the shelter. The peaks of the shelter resonance spectrum dominate the high frequency range.

The mathematical model is based on a finite difference representation of Maxwell's equations together with the external currents across shelter seams and seam transfer impedance as the physical source of the internal excitation. These calculations are compared with an experimental pulse waveform and independent seam impedance measurements as the verification of the model.

EFFECTS OF DIELECTRIC LOADING ON RESONANCES IN THE CONCENTRIC SPHERICAL CAVITY

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An analytic study of coupling of electromagnetic radiation to enclosed elements, consequent to penetration through apertures in a shield, is being pursued. Several results obtained during the course of the study shall be reported.

For a small aperture one naturally expects the internal resonant frequencies to be very nearly those of the closed system. Hence a study was made of the resonances of a simple canonical system and effects induced by varying the size of an enclosed element were observed. Further, dielectric loading was introduced in the interior and the effects on the cavity resonances determined.

Results shall be given for the simple geometry of a conducting sphere containing a concentric spherical conductor with varying size of inner radius. Effects due to separately cladding the interior sphere and the outer conductor with a dielectric layer shall be shown and compared for different dielectric strengths and layer thicknesses. The results display a variety of characteristics of practical significance in understanding coupling phenomena.

EXPERIMENTAL STUDIES IN EM COUPLING THROUGH APERTURES, SLITS AND SEAMS*

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A key factor in being able to predict the vulnerability of military systems to electromagnetic threats involves the phenomenology of how the energy penetrates through back door ports of entry (POE's). This presentation focuses on coupling through apertures, slits and seams.

The onset of the most significant penetration through these POE's occurs when they become resonant, and the response with frequency depends on the POE's size and shape. Below resonance their shielding effectiveness can be appreciable. Coupling tends to peak near resonance depending on the Q of the POE. In turn, this Q is a function of the aspect (length/height) ratio. Above resonance these POE's often offer little shielding effectiveness and energy simply "shines through."

Experiments were made on coupling through a variety of such POE's in a plane and in a cylindrical cavity using the broadband (0.1→18 GHz) EMPEROR Laboratory at Lawrence Livermore National Laboratory. These results will be compared with some modeling predictions, and the phenomenology of the coupling effects will be explained.

Once the energy penetrates the POE, it can couple to wires and cables. Results will also be given for these cases, and the phenomenology interpreted in terms of the SEXCE predictive model which will be explained in another presentation at this meeting. Finally, in an enclosed system the energy which penetrates a POE rattles around inside the enclosure, creating still another aspect of the overall coupling problem.

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*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 funded by The Defense Nuclear Agency, IACRO 86-837.

CONSIDERATIONS FOR A HEMP SYSTEM-LEVEL FIGURE OF MERIT

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In addition to the initial cost of designing, fabricating, and manufacturing the hardening elements, the true cost of HEMP hardening includes the cost of maintaining and verifying the hardening after it is operating in the field. Because it is often difficult to assign costs to activities beyond the design process, the determination of realistic total system hardening costs may also be difficult. Furthermore, the only measure of the value received for these costs has been an assurance that the hardening meets the system requirements. In the absence of other justification, a procuring office weighing several alternative designs would probably select the lowest-cost alternative.

A systematic way to establish the value of HEMP hardening is needed, so that procuring agencies can balance cost against value. The value of HEMP hardness is postulated to be highest if (1) there is high confidence that the hardness exists; (2) the hardness is resistant to change because of use, environment, age, wear, lack of prescribed maintenance, and other expected situations; and (3) the hardening elements require little maintenance.

This paper describes factors that contribute to the notion of HEMP life-cycle hardening value. These factors are described in semi-quantitative terms which produce a useful engineering checklist and a means of judging the merit, in an EMP hardening sense, associated with similar design features in two or more candidate designs. The checklist can be used by a procuring agency to identify a good HEMP-hardening design and to review and evaluate contractors' designs so that a relative confidence in the HEMP hardness can be established. It can also be used by design engineers to ensure that they have considered the elements necessary to produce a design consistent with low-risk HEMP hardening.

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EMP TEST OF FAST PATROL BOATS

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EMP testing of two Fast Patrol Boats (FPB) was carried out in 1982. One of the FPB's was old and had a simple EMC protection. The other was comparatively new with an extensive EMC protection.

A transmission line simulator was erected over the vessels. It was confirmed by the test that the seawater could be used as the lower plate (ground plane). The tests were carried out with a peak vertical EMP field strength of about 5 and 10 kV/m.

Mapping of fields and measurements of current and voltage in important circuits were carried out with a field strength of 5 kV/m. This was done at various points (about 60) exterior and interior to the hull. Finally a functional check-out of all major electrical and electronic systems was performed at the 10 kV/m field strength level.

Some results of field mapping and measurements are presented together with a description of main results of system assessments. Measurements on various antennas and conductors are compared with results from a theoretical prediction study.

Protective measures were specified after evaluation of test results. The principle of these measures will be described.

MEASUREMENT OF SEAM IMPEDANCES OF TACTICAL SHELTERS FOR THREAT LEVEL NEMP SIMULATION

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In order to successfully model internal field responses of shelters in an NEMP environment, seam transfer functions must be accurately known.

A discussion of several methods which recently have been developed for this task include internal seam voltage measurements using AESOP excitation and the seam impedance measurement method (SIMM).

Data giving typical seam impedance values for an S280 shelter are presented. It is concluded that reliable measurements of this fundamental quantity needed in determining shelter shielding effectiveness can be made under laboratory conditions.

CALCULATED INTERNAL RESPONSE OF AN ARC-SPRAYED ZINC SHELTER

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ABSTRACT

The electromagnetic field response has been calculated for a small building which was shielded by arc-spraying the interior with a thin layer of zinc. The calculations are based on a finite difference representation of Maxwell's Equations and a thin layer convolution representation for the transfer impedance of the metallic zinc layer. The response shows the diffusion fields with time constants much longer than the source pulse width. Results are given for several different points inside the shelter. The induced current in a straight wire along the inside length of the shelter is also given. The higher frequency propagating modes inside the shelter are also evident in the response curves for both the electric and magnetic fields.

THE CASE FOR IDENTIFYING CONTACT IMPEDANCE AS THE MAJOR ELECTROMAGNETIC HARDNESS DEGRADATION FACTOR?

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The purpose of this study was to identify the factor that is both the most likely to change during the life of a system and is a dominant electromagnetic coupling mechanism. The approach used was to examine experimental data on shielding of cables, cableways and enclosures and look for coupling mechanisms that could change during the life of the system. The conductivity, permeability and thickness of a shield will not change, therefore diffusion coupling and shield resistance will not change. The high frequency electromagnetic performance of most cable shields is limited by porpoising coupling, not apertures. Porpoising coupling is determined by the contact impedance between braid wires. Even in aperture dominated cable shields, apertures do not change significantly with use. Connector/backshell measurements are dominated by contact impedance. Cableway measurements show that contact impedance dominates over most of the EMP frequency range. Measurements of equipment boxes and racks showed that the electromagnetic performance was determined by the contact resistance of the joints over most of the EMP frequency range. Conductive penetrations are a major path for coupling exterior skin currents to interior cables in aircraft. The amount of current that is coupled through a shield is directly proportional to the impedance between the conductor and the shield. Experience has shown that mating surfaces must be deformed in order to achieve the "ultimate" transfer impedance. Examination of the possible coupling mechanisms through a shield shows that contact impedance is the factor that is most likely to change during the life of the system. This change can occur because of oxidation/corrosion or mechanical damage of the mating surfaces. Unfortunately, contact impedance is poorly understood, especially when compared to other coupling mechanisms.

An examination of a wide range of experimental data shows that contact impedance rather than enlargement of apertures or changes in material conductivity appears to be the major electromagnetic hardness degradation factor. It is also the least understood.

A SIMPLE THEORY FOR PREDICTING THE ELECTROMAGNETIC PERFORMANCE OF ENCLOSURES USING IMPEDANCE AND POLARIZABILITY MEASUREMENTS

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Electromagnetic analyses frequently use magnetic field attenuation to specify the performance of enclosures. The magnetic field attenuation is the ratio of the surface magnetic field on the exterior of the enclosure to the magnetic field inside. This quantity is often more useful than shielding effectiveness for electrically small enclosures because it eliminates the external coupling from the specification/prediction.

In 1982, Madle and Hoeft presented a simple theory for understanding the magnetic field attenuation of electrically small enclosures. This theory was semi-quantitative since it could predict the frequency dependence of the magnetic field attenuation and could predict the relative attenuation of various enclosures. This theory has been refined so that quantitative predictions can be made of the surface magnetic field attenuation of a wide range of enclosures. These enclosures include those with resistive joints, and both open and shielded apertures. The surface resistance and effective magnetic polarizability of aperture coverings, such as flame sprayed coatings and wire mesh, can be accounted for. This theory allows the definition of calibration panels whose electromagnetic performance is based on independent parameters, such as hole size and surface resistance. Similar calibration samples have been extremely useful for establishing the credibility of surface transfer impedance measurements of cables and connectors. The theory suggests that the definition, measurement and use of a surface transfer impedance, with units of Ohms/square, or surface transfer admittance, with units of mhos/square, may be advantageous.

Comparison between theory and experiment shows that reasonably good agreement is obtained for a wide range of enclosures.

On Grounding - Practical Procedures based on Electromagnetic Theory.

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For many years, grounding has been considered to be an engineering technique consisting of different sets of practical rules, not always self-consistent. The objective often seems to be rather nebulous which may count for the sometimes emotional influence on technical discussions.
On the other hand, the concept of controlled electromagnetic topology provides an opportunity to attain a unification of the grounding procedures. Grounding can be given a topologically significant definition which will constitute a relevant base for practical methods. Although the course to achieve practical and useful rules seems to be fairly straightforward, there are some obstacles in the way which have to be overcome.
The first issue to be considered is the difficulty in applying topological methods to a system that is designed without any consideration of electromagnetic topology. In order to be able to cope with that problem, the concept of a generalized shield is introduced. In electromagnetic topology, surfaces are considered to be boundaries virtually impervious to electromagnetic energy. In the generalized context, the boundaries do not have to consist of integral metal shields but some kind of hindrance to electromagnetic coupling.
The next question is how to narrow the gap between the theoretically formulated general grounding strategy and the engineering practice. The general shield provides an important element in transforming abstruse abstract formulations into practical grounding methodology.
At last, the most important objective of grounding is discussed. Once the purpose is determined, there will be no dispute concerning different methods of procedure. An integral approach which comprises different requirements on grounding is now possible to perform which will create a high system reliability with low life cycle costs.

Reference: Carl Baum, Topological Considerations for low-frequency Grounding and Shielding.

MILITARY AIRCRAFT SUBSYSTEM STANDARDS DEVELOPMENT

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ABSTRACT

The Aeronautical Systems Division (ASD) at Wright-Patterson AFB, Ohio, has prepared Notices for inclusion in MIL-STD-461B and MIL-STD-462 which address generic subsystem/equipment transient hardness requirements and test methods for aircraft application. In the near future, ASD will circulate the proposed documents throughout the Air Force for review and coordination. After the documents are published for Air Force use, ASD will submit the documents for tri-service review and coordination. The Notices are in response to Department of Defense tasking to the Air Force (ASD is the designated lead activity) to develop electromagnetic pulse (EMP) specifications and standards for military aircraft. The proposed changes are generic in that they do not specifically reference EMP due to their applicability to other transient environments such as lightning. Aircraft system-level EMP standards are presently under development.

CORRELATION OF MIL-STD-285 MEASUREMENTS, SEAM TRANSFER IMPEDANCE AND EMP SHIELDING EFFECTIVENESS

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ABSTRACT

A model for the penetration of shielded enclosures by electromagnetic fields is developed. The dominant sources are seams, each of which is characterized by its own transfer impedance. This parameter is used to relate shielding effectiveness determined by RFCW MIL-STD-285 measurements to the EMP case. The results of measurements and computer simulations for both RFCW and EMP demonstrate the efficacy of the technique.

A Practical, High-Reliability EMP Detector System

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An EMP detector system is a viable means of early warning by providing positive indication of high altitude events. In order for such a system to be a valuable addition to a strategic early warning system, it must be highly reliable, exhibit a practical producible design, incorporate built-in test equipment for functional verification and fault detection, and be easily installed and maintained by user agency field personnel.

The described system incorporates multiple redundant sensing to maximize reliability, and multiple voting among elements to minimize the probability of false alarm. Lightning discrimination is included in the basic design to minimize the probability of false triggering from lightning events. Flexibility of the design allows the use of one, two, or three individual sensors in the system without modifications.

The sensor unit is environmentally and electromagnetically protected allowing placement in virtually any location. Its physical construction allows mounting on any flat surface without special accommodations. The controller elements are individually hardened to EMP/EMI to provide trouble free operation in high EM environments without the need to provide costly, high maintenance screened environments. The total controller requires approximately 24 inches of non-hardened 19-inch rack space.

Interconnection between the sensor unit and the controller is via conventional rigid electrical conduit and standard video cable. Three cables are required for sensing and one for self test. All connections are made via simple, screw type terminal strips and crimp-on terminals. Signaling is done using current loop techniques resulting in an extremely reliable design of minimum complexity. The need for separate power and signaling lines is eliminated. The requirement for batteries in the sensor unit is eliminated allowing the sensor unit to be a totally sealed system.

The system operates from either nominal 12V DC or from AC mains of 120V to 240V, 50 Hz to 400 Hz. This allows operation in almost any land or sea based site where such a unit might be of value.

Built-in test equipment continuously monitors various parameters and provides real time indication of the system's current status as well as historical status for ease of fault isolation and maintenance. This also allows a positive test of the individual sensing circuits from the controller.

This work was sponsored by the Air Force Weapons Laboratory under Contract F29650-84-DE005.

MODULAR DATA SYSTEM (MDS)

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A high-speed Modular Data System (MDS) for recording EMP response and other EM phenomena is being developed by the Air Force Weapons Laboratory. This CAMAC-based instrumentation system will be used for EMP testing of the aircraft and AFWL EMP Test Bed Aircraft (EMPTAC). A single, 19-inch wide CAMAC crate can support three complete high-speed transient recording channels.

Each recording channel is based on a charge coupled device (CCD) A/D design from the current state-of-the-art transient recorder. The recorder has a 250 MHz bandwidth using a 1.35 GHz sample rate for 10,000 samples and 7.5 bit effective resolution. The signal condition has a 5 dB noise figure, better tahn 36 dB harmonic distortion at 0 dBm and better than 100 kHz to 250 MHz bandwidth. The signal conditioner has independent control of gain, attenuation and frequency response for integration and differentiation that are optimized for EMP measurements. High-data acquisition rates are possible through the use of four, 16 port remote coaxial switches (RCS). Each RCS is fiber optic controlled from the signal conditioner unit. Any one of up to 64 sensors can be selected as input into the signal conductor.

Control of this system is programmable with a computer via a GPIB fiber optic bus extender or manually from the front panel switch and display. Complete verification hardware and software is built into the system to ensure high data integrity.

Telemetry Control System (TCS)
A Highly Automated Data Acquisition Approach

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EG&G Washington Analytical Services Center, Inc., has developed a Telemetry Control System for the Defense Nuclear Agency which automates the control functions required to support data acquisition within the context of the EMP Test Environment.

The control system consists of a high-speed, 16-bit minicomputer as controller and three, ten-megabyte disc drives for data storage housed within a shielded rack enclosure. A combination of custom software and a powerful database management software package is used to exercise control over the external data acquisition system. Fiber optic links are used to connect the control system to two multichannel data acquisition systems consisting of an eight-channel data link controller and an eight-channel, log-weighted, peak-level recorder. A single point of control is provided by a fiber optic connection to a shielded terminal (located near the test object) from which the Test Director can guide the test and view the detected peak level values as they are acquired. The TCS uses these peripheral devices in real time to control the system gain and acquire bipolar peak level data from remote test points. The system design provides enough flexibility to allow for deviations from, and additions to, the test schedule while the test is in progress.

The operating system used by the TCS supports a multiuser environment so that the capabilities of the database management software may be used while data are being acquired. In addition to data editing, sorting, and searching, these capabilities include the generation of a number of standard and creative report formats.

The system became operational in the third quarter of 1985.

This work was sponsored by the Defense Nuclear Agency under Contract DNA001-83-C-0111..

ELECTROMAGNETIC LABORATORIES AND MEASUREMENT TECHNIQUES FOR COUPLING PHENOMENOLOGY*

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An overview of the LLNL broadband simulator laboratories and coherent diagnostic techniques will be described. The application of these technologies to coupling phenomenology studies using generic and scale model test objects will be described, but the actual test results will be deferred to companion papers to be presented at this meeting.

The EMPEROR Laboratory will be described first. This is a large (3m high) broadband (0.1÷18GHz) constant gain monocone radiator situated over a ground plane and shrouded with low frequency microwave absorber which mitigates undesired reflections from the walls, ceiling, ground plane edges, etc. It can be operated in either the time or frequency domain modes. In the time domain, the source is a high voltage, fast rise time repetitive pulser, and the diagnostics center around a microwave frequency sampling oscilloscope. In the frequency domain, a 20 mW synthesized source is used in conjunction with a state of the art coherent automatic network analyzer diagnostics system with peripheral computer controls, data storage/management/processing equipment.

For greater flexibility of test object configurations, and to permit studying the effects of polarization, incidence direction, etc., the microwave (1÷18GHz) anechoic chamber is used. This too is equipped with a state of the art automatic network analyzer and associated computer controls, pattern plotters, and data storage/management/processing equipment.

We will conclude with a description of a broadband (2÷18GHz) coherent instrumentation system being developed to map field components inside apertures and cavities, and for measuring wire and surface current distributions. This tool will be useful for understanding the details of coupling effects and for validating numerical modeling codes.

*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 funded by The Defense Nuclear Agency, IACRO 86-837.

Recent Developments in Automated Continuous Wave Illumination Test Systems

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The Swiss Confederation and the U.S. Naval Surface Weapons Center, with support from EG&G and Science Engineering Applications, Inc. (SEA), have developed highly automated systems for CW illumination control and data acquisition. Each system operates under computer control utilizing a database management system to store and execute "Test Plan" defined parameters. This approach minimizes execution errors and produces a higher data acquisition rate than previous CW systems used in the stepped mode. Flexibility is designed into the system to permit those changes in test plans that inherently occur in any field test program. These changes are entered with a minimum of operator interaction. Operator data entry during testing is normally accomplished with responses to as few as three prompts.

This database approach, coupled with state-of-the-art network analyzer hardware provides the capability to take measurements of improved sensitivity, with greater accuracy and at a higher data rate than previously possible. The data are corrected for all instrumentation effects to produce, in real time, an output showing the measurement quantity, in corrected units, at the measurement point. The data are then stored on disk and key parameters are saved in the database system from which detailed or summary reports can be produced on demand.

An "Analyst Package" of software tools also is included which provides capabilities for:

- Scaler and vector operations on data in time or frequency domains.
- Forward and Inverse Fourier Transforms
- Complete plotting capability including multiple plot overlays.

This work sponsored in part by the U.S. Naval Surface Weapons Center under Contract N60921-84-C-0056.

Integrated Software for EMP Test Planning,
Data Acquisition, and Data Analysis
A Program Overview

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EG&G, Inc. has developed an integrated software solution to the problems of EMP test planning, data acquisition and analysis. The software supports both CW and pulse data acquisition systems within the same operational environment.

The software consists of a full-featured database management system which facilitates test planning, data management and test reporting; programs to perform the data acquisition tasks; and a package of programs for test data analysis.

The software runs on Digital Equipment Corp. PDP-11 series minicomputers running the RSX-11M/M+ operating system and makes use of standard EMP data acquisition hardware such as programmable transient digitizers and network analyzers. A similar system is under development to run on the VAX series of computers.

The software design permits concurrent data analysis, data acquisition and data management functions. Graphics terminals, plotters, manual digitizing tablets, printers and magnetic tape drives are supported, as well as a variety of fixed and removable disk drives. IEEE-488 bus capability is a standard feature.

This work was sponsored in part by the U.S. Naval Sea Systems Command under Contract N00024-84-C-5357.

EXPERIMENTAL AND THEORETICAL TECHNIQUES FOR DETERMINING COUPLING THROUGH APERTURES IN CYLINDERS

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The problem of the interaction of a plane wave with an aperture in an infinite cylinder has received much attention. There are numerous results presented in the literature for different approaches to this problem. There is, however, little presented on coupling of near-field distributions to this same structure. The motivation of this work is to develop numerical and experimental approaches for coupling of either near or far fields through an aperture in an electrically long cylinder.

Experimental techniques include microwave field probes, infrared detection of electric fields, and standard voltage measurements. The infrared technique involves thin resistive materials placed in the aperture and scattered regions for the detection of the electric field through joule heating. Time-varying magnetic field probes are used to provide additional dynamic range. The voltage on the axial wire provides a direct indication of coupled field strength. Thus, measurements are made of fields scattered from the structure, field distributions in the aperture, and voltages on the axial wire.

The electric field distribution is calculated in the near field of a horn antenna. This is chosen to facilitate comparison with experiment. The method of moments computer code NEC2 and a code for determining the field patterns from a horn, developed as part of this work, are the bases of the numerical solution.

Several special cases are considered. Results are presented first for the far field. An analytical solution is presented for plane wave coupling and both numerical and experimental results are presented for far-field patterns. Comparison of these results is necessary to show agreement for a simple spatial field distribution. Experimental and numerical results are then presented for near-field patterns.

TM TRANSMISSION THROUGH DIELECTRIC FILLED SLOTS IN CONDUCTING CYLINDERS OF ARBITRARY CROSS SECTION

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A simple moment solution is given to the problem of electromagnetic transmission through a dielectric filled slot in a conducting cylinder of arbitrary cross section. Only TM case is considered. The exciting source is assumed to be either a TM plane wave (receive mode) or an electric line source placed inside the cylinder (transmit mode).

The surface equivalence principle is used to replace the conducting and the dielectric cylinders by equivalent surface currents. A set of coupled integral equations is obtained by using appropriate boundary conditions on the surfaces of the cylinders. The method of moment, with pulse expansion and point matching techniques, is used to solve the integral equations for the equivalent surface currents. These currents radiating in an unbounded medium are considered to be the sources of the scattered field.

Cylinders of different cross sections are considered. Special attention is paid to a circular or rectangular conducting shell with a slot filled with dielectric material. In the transmit mode the total far field transmitted through the slot is computed. For the receive mode, the aperture field and the field at the center of the cylinder are computed. For the case of air dielectric the computed results are in very good agreement with published data. For other dielectrics a comparison was not possible.

NEAR FIELD COUPLING OF ELECTROMAGNETIC PULSE TO CABLES FROM CIRCULAR APERTURES

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Abstract

Electronic system designers introduce apertures while designing subsystems cases, equipment racks, building that house the electronic systems. Electromagnetic Pulse energy penetrates through these apertures and couple to cable loops and circuits placed inside the equipments.

In this paper an attempt is made to compute the near field coupling of Electromagnetic Pulse (EMP) to cable loops from nearby circular apertures. The aperture is assumed to be in the Z=0 plane and X directed EMP waveform is assumed to be present across the aperture. The EMP waveform is sampled and the Fourier transform is then computed using FFT algorithm. The coupling calculations are carried out using plane wave spectrum (PWS) approach at each of these discrete frequencies assuming the cable 'loop' at a distance 'd' from the aperture and is centrally placed at the point of calculation.

In this plane wave spectrum approach the aperture field at a given frequency is decomposed into a spectrum of plane waves. The plane wave spectrum is then transferred to a distance 'd' where the cable loop is present. Using the known plane wave coupling technique, aperture field at each of the discrete frequencies coupled into the cable is then calculated. Finally, the time domain waveform is computed using IDFT algorithm.

The paper also discusses computational considerations involved in computing the discrete fourier transform of the EMP waveform and the plane wave spectrum. In addition, this paper also examines how this method can be extended to situations where more than one aperture is present. The paper highlights the design of apertures using waveguide below cutoff techniques to reduce the EMP penetration through apertures to an acceptable level.

NEAR-FIELD COUPLING TO LOADED WIRES BEHIND SLOTS

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A method is presented for calculating an upper bound on the current induced by the EMP in a wire mounted close behind a slot in a shield.* The method assumes that the slot and wire act as an antenna and a load impedance. Measurements demonstrate that the calculated upper bounds are less than a factor of two greater than actual induced currents. Hence, these calculations yield useful, conservative upper bounds on coupling.

*Taylor, C. D., "On Bounding the Excitation of Wiring Behind an Aperture in a Shield From Lightning-Induced Fields," 1984 International Aerospace and Ground Conference on Lightning and Static Electricity, pp. 36-1 through 36-4 (June 1984).

THE EFFECTS OF CAVITY FILL AND DIELECTRIC APERTURES ON MICROWAVE COUPLING*

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In Lawrence Livermore National Laboratory's ongoing study of electromagnetic coupling phenomenology, broadband (0.1→18 GHz) measurements were made in the EMPEROR Laboratory on various configurations of a generic test object. This test object, known as PLUTO, is a right circular cylinder having a 10:1 length/diameter ratio. It can be configured with various ports of entry and internal cavity sizes, fill and wires/cables. This presentation focuses on the effects of metalic and lossy fill inside the cavity, and on loading the port of entry (aperture) with dielectrics.

In the experiments dealing with metal fill, the effect of placing various configurations of right circular cylinders in the cavity were studied. It was generally found that such fill only offers appreciable shielding if it tends to block the port of entry. Otherwise, the size and location of the metal fill has little effect on the average coupling to a wire/cable.

The effects of introducing lossy materials at various positions in the cavity was also measured. This lossy fill ranged from ferrite materials wrapped around wires to partially filling the cavity with polyfoam microwave absorber material. In general, such lossy material only moderately improves the shielding effectiveness above a few GHz, and is most effective when the material blocks the aperture.

Finally, experiments were done in which the aperture was loaded with various dielectrics. These results will be compared with some numerical modeling predictions.

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*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 funded by The Defense Nuclear Agency, IACRO 86-837.

FREQUENCY DEPENDENT MAGNETIC FIELD ATTENUATION BY A METALLIC CYLINDRICAL CHIMNEY APERTURE

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An analytic model has been developed to evaluate the frequency dependent attenuation of a magnetic field traversing a chimney aperture.

Kaden[1] developed a frequency independent model for evaluating the attenuation of the magnetic field due to the chimney aperture using a scalar potential. In this work, a vector potential has been evaluated from the Helmholtz equation. Its z-component is similar to Kaden's scalar potential except the decay constant, α, is dependent upon the frequency of the incoming magnetic field which has an assumed sinusoidal time dependence. The z-component is given by

$$A_z = \text{Const} \cdot J_1(\beta\rho)\ e^{-\sqrt{\alpha}\ Kz} \sin\phi\ \cos\omega t \tag{1}$$

where

$$\beta = \sqrt{1-\alpha}\ K . \tag{2}$$

The normal component of the H-field is obtained from

$$\nabla \times \vec{A} = \vec{H} . \tag{3}$$

Applying the boundary condition $H_\rho = 0$ at $\rho = r_o$ gives

$$\beta = \frac{R_n}{r_o} \tag{4}$$

where R_n are the zeros of the Bessel function of order 1 and r_o is the radius of the chimney.

Substituting (4) into (2) and solving for α we have as the damping function g(z;f)

$$g(z;f) = \exp[-(R_n^2 - (\frac{2\pi f r_o}{c})^2)^{1/2} \cdot \frac{z}{r_o}] \tag{5}$$

provided

$$f < \frac{cR_n}{2\pi r_o} \tag{6}$$

Equation (5) predicts both the expected high and low frequency limits and in addition predicts a greater attenuation than does Kaden's results.

The reason the greater attenuation occurs is due to the manner in which the H-fields were derived.

Because Kaden assumes the H-field is determined by a scalar potential the boundary conditions require that the Bessel function's derivative vanish at the boundary instead of the Bessel function itself. The zeros of the derivative are always less than the zeros of the function thus resulting in the difference in attenuation.

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[1]Kaden, Heinrich, Wirbelströme und Schirmung in der Nachrichtentechnik, Springer-Verlang, 1959.

SCATTERING FROM AN OPEN SPHERICAL SHELL HAVING A CIRCULAR APERTURE AND ENCLOSING A METALLIC OR DIELECTRIC SPHERE*

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Canonical electromagnetic scattering problems are important from several points of view. They provide basic understanding of scattering processes which can be extrapolated to more general geometries. Moreover, they provide fundamental benchmarks for general purpose scattering codes. However, there are few fully three-dimensional scattering problems for which solutions have been found, especially when the scattering body includes an aperture.

The solution to the scattering of a normally incident plane wave from a perfectly conducting spherical shell having a circular aperture has been obtained by Ziolkowski and Johnson [submitted to J. Math. Phys., July, 1985]. It is based upon an essentially analytic solution of the coupled dual series equations for the TE and TM modal coefficients arising from the enforcement of the electromagnetic boundary conditions over the aperture and the shell. That solution has been extended to the cases where the open spherical shell encloses a concentric, perfectly conducting mettallic sphere or a concentric homogeneous, lossless dielectric sphere [Ziolkowski, Peplinski, and Libelo, URSI Meeting, Boulder, CO, Jan. 1986].

The normal incidence cases of these extensions have been studied extensively in regards to EMP coupling issues. The results of this investigation will be presented in this paper. In particular, the scattering and coupling data [cross-sections (total, forward and back), the energy density ratio at the origin, and the energy stored in the open shell as functions of ka (2π x shell radius / wavelength)] are dominated by resonance features that depend upon the characteristics of the interior sphere. It has been established that these resonance features are common to all of the cavity-backed aperture geometries that have been studied to date. It will be shown how the locations of the resonance features change as the radius and/or the dielectric constant of the interior sphere and the aperture size change. The results are closely related to the resonant mode behavior of the corresponding closed spherical cavity cases. The effect of these resonance features on time domain data will also be discussed.

* This work was performed in part by the Lawrence Livermore National Laboratory under the auspices of the U.S. Department of Energy under contract W-7405-ENG-48 and by Harry Diamond Laboratories.

NUMERICAL SIMULATION OF NON-LINEAR COUPLING OF INTENSE MICROWAVE PULSE THROUGH APERTURES*

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The electromagnetic phenomena induced near an aperture by a low energy microwave pulse (the amplitude of the electric field below the threshold for air breakdown) can be adequately treated by the linear coupling theory based on Maxwell's equations. However, if the intensity of the microwave pulse causes the enhanced field in the aperture to exceed the air breakdown threshold, the linear coupling theory is no longer adequate and Maxwell's equations alone are not sufficient to describe the physics correctly. The electron transport equations describing the interaction of electrons with the electromagnetic field and the air molecules must be solved simultaneously with Maxwell's equations to describe the ionization process correctly. These transport equations can either be the Boltzmann equation or the electron fluid equations of continuity, momentum conservation and energy conservation.

The purpose of this paper is to present some results of our recent numerical investigations of air breakdown near the aperture of some two dimensional waveguide irises obtained from solving Maxwell's and the electron fluid equations. Two approaches were used in our investigations. One is based on a finite difference technique; the other on finite element techniques. Computer results showing how the electron density and the field components vary near the aperture during the air breakdown process will be presented. The effect of air pressure on the amount of energy transmitted through the aperture will also be given.

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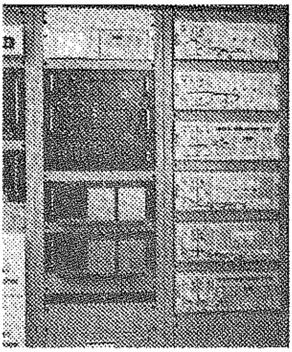
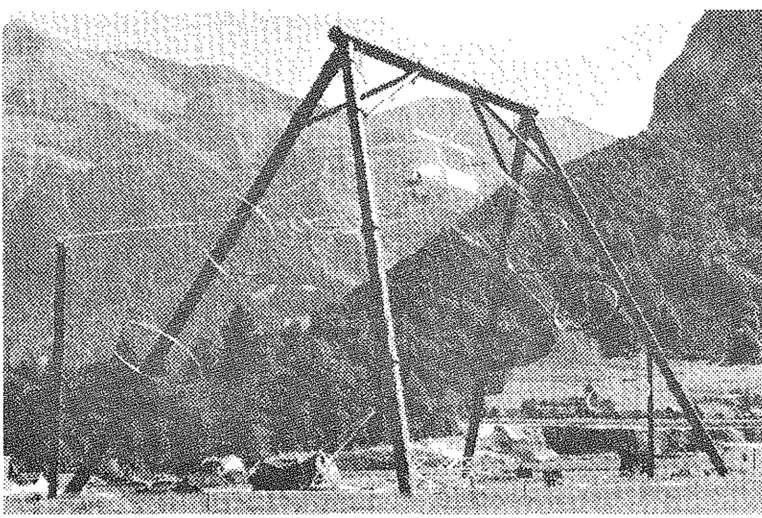
*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48, and funded by The Defense Nuclear Agency, IACRO 86-837.





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