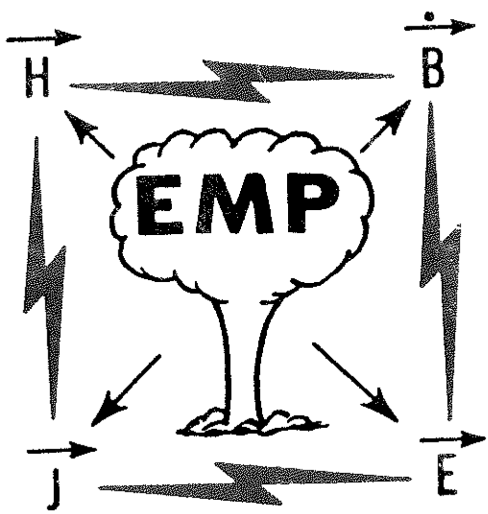
NEM 1990 RECORD

ABSTRACTS OF TECHNICAL PAPERS

Nuclear EMP Meeting

May 21-24, 1990

University of New Mexico
Albuquerque, New Mexico



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SUNDAY, 20 May	MONDAY, 21 May	TUESDAY, 22 May	WEDNESDAY, 23 May	THURSDAY, 24 May	FRIDAY, 25 May
8:30 a.m.-12:10 p.m.	Room 101 NEM-1A Simulation Modeling NEM-1D Simulators Room 103 NEM-1B, E-1 Cable Coupling: Experimental Characterization NEM-1E, E-2 Cable Coupling: Multiconductor Lines Room 104 NEM-1C, E-3 Environments & General Topics	Room 101 NEM-3A Fast Pulse Simulation Room 103 NEM-3B System Testing - I NEM-3C, E-5 Interaction II: Norms PERMANENT NEM COMMITTEE LUNCHEON 12:00-1:30 p.m.	NEM-P1, E-9 PLENARY SESSION STUDENT UNION BALLROOM	Room 101 NEM-6A Data Acquisition & Processing - I Room 103 NEM-6B System Testing - II Room 104 NEM-6C Radar Target Discrimination	TOURS
1:30-5:00 p.m.	Room 101 NEM-2A Modeling for Low-Level Simulators Room 103 NEM-2B, E-4 Interaction I: General Room 104 NEM-2C HPM NEM-2D Sensors	Room 101 NEM-4A, E-6 Subsystem Test Devices Room 103 NEM-4B, E-7 Specifications & Standards NEM-4C, E-8 Specifications & Standards Panel	Room 101 NEM-5A, E-10 Testing Room 103 NEM-5B, E-11 HPE Panel	Room 101 NEM-7A Data Acquisition & Processing - II Room 103 NEM-7B, E-12 Hardening	
REGISTRATION RECEPTION CLARION FOUR SEASONS HOTEL 6:00-9:00 p.m.	RECEPTION MUSEUM OF NATURAL HISTORY 6:00-9:00 p.m.		CONFERENCE BANQUET KIRTLAND AFB EAST OFFICER'S CLUB 6:30 p.m.	INTERNATIONAL GUEST RECEPTION 7:30 p.m.	

NEM 90

On behalf of the Organizing Committee for NEM 90 and the Permanent NEM Committee, I would like to welcome you to the seventh Nuclear Electromagnetic Pulse Meeting, the fourth to be held in Albuquerque. We are doing our best to maintain the standards of hospitality and cordiality established in the past. The technical agenda for the meeting reflects the changing emphasis on electromagnetic threats to defense and civilian systems. There is more attention being paid to transient or pulse-related threats which are non-nuclear in origin. It is our intention to provide the most congenial atmosphere possible for you to absorb and reflect upon the new and updated information being presented. We hope your stay in Albuquerque is a pleasant one and is capped off with a number of new friends and acquaintances.

Michael G Harrison

M.G. Harrison, Chairman

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

Selected sessions of this conference are jointly sponsored by NEM and by the U.S. National Committee of URSI, Commission E. These sessions are designated by both NEM and URSI (E-_) session numbers.

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TECHNICAL PROGRAM

MONDAY, 21 May
8:30 - 10:00 a.m.

SIMULATION MODELING

Session NEM-1A
Room 101

Chairman: J. Shiloh
Rafael, Haifa, Israel

		Page
8:30	Session Introduction	
1. 8:40	**An Exact Method for Calculating the Fields of a Wide Angle Biconical Antenna with Resistive Loading**, I. Kohlberg, Kohlberg Associates, Inc., Alexandria, VA	1
2. 9:00	**The External Field Environment of VPD-II,** K F. Casey, JAYCOR, Fremont, CA; and M.J. Sabochick, Air Force Institute of Technology, Wright-Patterson AFB, OH	2
3. 9:20	**Electromagnetic Modeling of Reflecting and Diffracting Fences Which Reduce the Far Fields of EMP Simulators**, I. Kohlberg and P. Elliot, Kohlberg Associates, Inc., Alexandria, VA; and T. Waltemyer, Harry Diamond Laboratories, Woodbridge, VA	3
4. 9:40	**A Numerical Method for Calculating the EM Field Radiated by EMP Simulator,** S.R. Zhang and W.Y Wang, Institute of Electronics, Academia Sinica, Beijing, China	4
10:00	Break	

MONDAY, 21 May
8:30 - 10:00 a.m.

CABLE COUPLING: EXPERIMENTAL CHARACTERIZATION

Session NEM-1B, E-1
Room 103

Chairman: E.F. Vance
SRI International, Menlo Park, CA

MONDAY, 21 May
8:30 a.m. - 12:10 p.m.

ENVIRONMENTS AND GENERAL TOPICS

Session NEM-1C, E-3
Room 104

Chairman: M.W. Wik
Defense Materiel Administration, Stockholm, Sweden

MONDAY, 21 May
10:30 a.m. - 12:10 p.m.

SIMULATORS
Session NEM-1D
Room 101

Chairman: R.W. Shoup
Defense Nuclear Agency/NMRS, Kirtland AFB, NM

MONDAY, 21 May
10:50 a.m. - 12:10 p.m.

CABLE COUPLING: MULTICONDUCTOR LINES

Session NEM-1E, E-2
Room 103

Chairman: D. Hansen
Asea Brown Boveri Ltd., Baden, Switzerland

MONDAY, 21 May
1:30 - 3:50 p.m.

MODELING FOR LOW-LEVEL SIMULATORS

Session NEM-2A
Room 101

Chairman: I. Kohlberg
Kohlberg Associates, Inc., Alexandria, VA

MONDAY, 21 May
1:30 - 4:50 p.m.

INTERACTION I: GENERAL

Session NEM-2B, E-4
Room 103

Chairman: J. Nitsch
NBC Defense R&D Institute, Fed. Rep. of Germany

MONDAY, 21 May,
1:30 - 3:00 p.m.

HPM

Session NEM-2C
Room 104

Chairman: L. Libello
Harry Diamond Laboratories, Adelphi, MD

MONDAY, 21 May
3:30 - 4:50 p.m.

SENSORS

Session NEM-2D
Room 104

Chairman: J.C. Giles
Los Alamos National Laboratory, Los Alamos, NM

TUESDAY, 22 May
8:30 - 10:50 a.m.

FAST PULSE SIMULATION

Session NEM-3A
Room 101

Chairman: Y.G. Chen
Maxwell Laboratories, Inc., San Diego, CA

TUESDAY, 22 May
8:30 a.m. - 11:10 p.m.

SYSTEM TESTING - I
Session NEM-3B
Room 103

Chairman: W.J. Karzas
Metatech Corporation, Santa Monica, CA

TUESDAY, 22 May
11:10 a.m. - 12:10 p.m.

INTERACTION II: NORMS

Session NEM-3C, E-5
Room 103

Chairman: K.S.H. Lee
Kaman Sciences Corp., Dikewood Div., Santa Monica, CA

TUESDAY, 22 May
1:30 - 5:10 p.m.

SUBSYSTEM TEST DEVICES
Session NEM-4A, E-6
Room 101

Chairman: D.E. Merewether
Electro Magnetic Applications, Inc., Albuquerque, NM

TUESDAY, 22 May
1:30 - 3:50 p.m.

SPECIFICATIONS AND STANDARDS

Session NEM-4B, E-7
Room 103

Chairman: W.D. Prather
Weapons Laboratory/NTAA, Kirtland AFB, NM

TUESDAY, 22 May
3:50 p.m.

PANEL ON SPECIFICATIONS AND STANDARDS

Session NEM-4C, E-8
Room 103

Chairman: W.D. Prather
Weapons Laboratory/NTAA, Kirtland AFB, NM

This panel will address both the current state of standards and specifications in the areas of EMI/EMC/EMP and future directions that are envisioned. Current work in the area of standards and specifications, including international efforts, will be discussed.

Panel Members (tentative):

- George Baker, Defense Nuclear Agency
- Dennis Baseley, Aeronautical Systems Division, USAF
- James Brackett, Harry Diamond Laboratories
- Robert Haislmaier, NAVAIR
- Juergen Nitsch, NBC-Defense Research & Dev.Inst.
- Manuel Wik, Swedish Defence Materiel Administration

WEDNESDAY, 23 May
8:30 a.m. - 12:00 p.m.

PLENARY SESSION

NEM-P1, E-9

Student Union Ballroom

Chairman: M.G. Harrison
Weapons Laboratory/NTCA, Kirtland AFB, NM

WEDNESDAY, 23 May
1:30 - 5:10 p.m.

TESTING

Session NEM-5A, E-10
Room 101

Chairman: D. Serafin
Centre d'Etudes de Gramat, Ministry of Defense, France

WEDNESDAY, 23 May
1:30 p.m.

PANEL ON HIGH POWER ELECTROMAGNETICS (HPE)

Session NEM-5B, E-11
Room 103

Chairman: A.W. Biggs
Weapons Laboratory/AWK, Kirtland AFB, NM

This panel will discuss extension and application of EMP technology to other areas.

Various technologies have been developed in the EMP community which have been used or have potential application in other areas such as lightning, EMI control, high power microwaves, and various wide bandwidth electromagnetic areas. These include transient electromagnetics, pulse power, and electromagnetic measurements.

Panel Members will include:

- C.E. Baum, Weapons Lab/NTAAB
- K.M. Chen, Michigan State University
- Y.G. Chen, Maxwell Laboratories, Inc.
- R.L. Gardner, Mission Research Corp.
- L. Libello, Harry Diamond Laboratories
- J. Nanevicz, SRII
- M. Skolnik, Naval Research Laboratory
- I.D. Smith, Pulse Sciences, Inc.
- R. Smith, U.S. Army Missile Command
- J. Swegle, Lawrence Livermore National Laboratory
- J.D. Taylor, LTC USAF, ESD/XTP

THURSDAY, 24 May
8:30 - 11:50 a.m.

DATA ACQUISITION & PROCESSING - I

Session NEM-6A
Room 101

Chairman: G.D. Sower
EG&G Special Projects, Albuquerque, NM

THURSDAY, 24 May
8:30 a.m. - 12:10 p.m.

SYSTEM TESTING - II
Session NEM-6B
Room 103

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

THURSDAY, 24 May
8:30 - 11:10 a.m.

RADAR TARGET DISCRIMINATION

Session NEM-6C
Room 104

Chairman: LTC J. Taylor
ESD/XTP, Hanscom AFB, MA

THURSDAY, 24 May
1:30 - 4:50 p.m.

DATA ACQUISITION & PROCESSING - II

Session NEM-7A
Room 101

Chairman: R.L. Hutchins
BDM International, Inc., Albuquerque, NM

THURSDAY, 24 May
1:30 - 3:50 p.m.

HARDENING
Session NEM-7B, E-12
Room 103

Chairman: P.J. Miller
TRW, Albuquerque, NM

AN EXACT METHOD FOR CALCULATING THE FIELDS OF A WIDE ANGLE BICONICAL ANTENNA WITH RESISTIVE LOADING

Ira Kohlberg, Kohlberg Associates, Inc., Alexandria, VA

A major element in the waveform design of a wide-angle biconical antenna used for EMP simulation is the resistive loading. This investigation deals with the development of a rigorous theory leading to the prediction of both the interior and exterior (far) fields of this type of resistively loaded antenna.

Schelkunoff appears to have been the first to develop a general theory for the biconical antenna in the absence of resistive loading. A fundamental aspect of the lossless case is that the interior fields are composed of modes of index u which are solutions of the equation

$$T_{u_i}(\cos\theta_0) = \frac{1}{2}\left[P_{u_i}(\cos\theta_0) - P_{u_i}(-\cos\theta_0)\right] = 0 \quad , \tag{1}$$

where θ_0 is the bicone angle, and the P_{u_i}'s are Legendre functions.

When resistive loading is included the interior boundary condition becomes

$$E_r(\theta_0) = E_r(\pi - \theta_0) = Z_w(r)\, I_w(r) \quad , \tag{2}$$

where $I_w(r)$ is the wall current and $Z_w(r)$ is the surface wall impedance. In the lossless case $Z_w(r) = 0$. We have formally solved the problem where Eq. (2) is applicable.

It is found that the resistively loaded case requires the existence of additional angular- and radial-dependent terms in the interior region (vis-à-vis the lossless case) in order to satisfy the interior boundary condition. The auxiliary θ-dependent terms are Legendre polynomials whereas the radial ones can be expressed in terms of an orthogonal basis of radial-dependent functions. These techniques reduce the determination of the interior and exterior fields to one which can be solved in matrix form.

The computational method is discussed along with the numerical method used to evaluate the basis functions, $T_{u_i}(\theta)$, for the lossless case.

THE EXTERNAL FIELD ENVIRONMENT OF VPD-II

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JAYCOR
39650 Liberty Street, Suite 320
Fremont, CA 94538

Michael J. Sabochick
Department of Engineering Physics
Air Force Institute of Technology
Wright-Patterson AFB, OH 45433

The electromagnetic field of the VPD-II EMP environment simulator is evaluated at observer locations far from the simulator and its working volume. The antenna surface current density distribution is determined by the resistive loading on the conical radiator; the feed-point current is determined from an equivalent circuit representing the pulser and the antenna input impedance. The field radiated by the antenna in the presence of the ground is evaluated in terms of an integral over the antenna currents. The field integral is then evaluated in the far zone of the antenna through the use of saddle-point integration. The resulting representation for the radiated field is interpreted in terms of "space wave" and "ground wave" contributions to the total field.

The space wave dominates the total field for observers well above the air-ground interface and is therefore of primary importance in determining the electromagnetic environment for aircraft. This field contribution decays as $1/r$. Its peak amplitude rises to a maximum as the observation angle, measured from the vertical, increases from zero to approximately 60° and remains nearly constant thereafter, up to observation angles of approximately 85°. The peak amplitude of the space wave then drops rapidly, vanishing at the air-ground interface.

The ground wave dominates the total field for observers within a few degrees of the air-ground interface and is therefore of primary importance in determining the electromagnetic environment for personnel and ground equipment. This field decays more rapidly than $1/r$ at long ranges. Ground losses and dispersion also degrade the rise rate of the ground-wave field as it propagates.

We present representative numerical data describing the total external field of VPD-II for observers well above, and close to, the air-ground interface at ranges up to a few kilometers from the antenna. Predicted environments are compared to existing and projected safety standards for personnel and aircraft.

ELECTROMAGNETIC MODELING OF REFLECTING AND DIFFRACTING FENCES WHICH REDUCE THE FAR FIELDS OF EMP SIMULATORS

Ira Kohlberg, Kohlberg Associates, Inc., Alexandria, VA
Paul Elliot, Kohlberg Associates, Inc., Alexandria, VA
Todd Waltemyer, Harry Diamond Laboratories, Woodbridge, VA

Recent environmental considerations are requiring that peak electric fields of EMP simulators be greatly reduced beyond the boundaries of the facility. In this study we examine a means for accomplishing this using various configurations of a chain link fence with the wires which form the apertures bonded at every junction, and of height equal to or greater than that of the simulator. Numerical results are keyed to AESOP, although the methodology is applicable to other simulators.

Figure 1 shows three of the designs which were analyzed. The vertical fence could be modeled analytically, but it was necessary to use numerical techniques for the configurations of Figs. 1b and 1c. The Method-of-Moments technique was used for frequencies below 100 MHz and the Geometric Theory of Diffraction was used for frequencies above 100 MHz.

As the height of the vertical fence was raised above the simulator a considerable reduction in the peak field occurred. This configuration, however, produced unacceptably strong reflections in the test volume.

The inward wedge fence produced the best suppression of the peak field as compared to the other configurations. For example, Fig. 2 shows the dramatic reduction of the peak field at 320 m from the simulator for an observer 10 m above the ground. The solid curve shows the rather minimal reduction of the peak field due to ordinary ground reflection. The fields in the test volume exhibited diffraction peaks of about 10% of peak of the incident field and modest interference from reflections.

The outward wedge yielded almost as good reduction of the peak far field as the inward wedge, and in addition provided excellent fidelity of the desired field in the test volume. This appears to be the best configuration for the models considered.

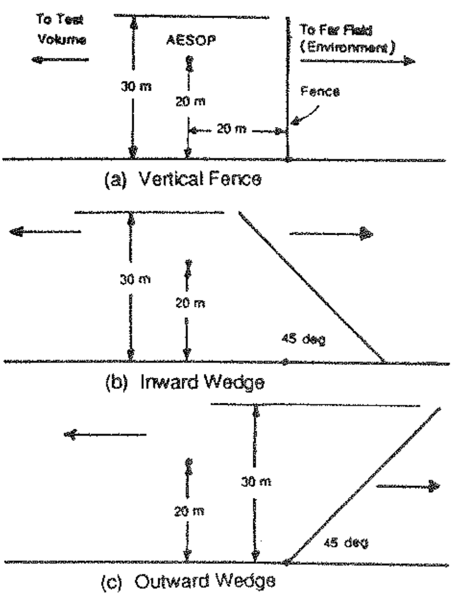

Figure 1. Fence Configurations

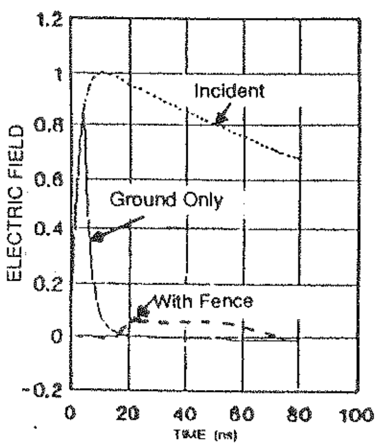

Figure 2. Electric Field 320 m in Front of Simulator, 10 m High, for Inward-Wedge Fence

A NUMERICAL METHOD FOR CALCULATING THE EM FIELD RADIATED BY EMP SIMULATOR

S.R.Zhang and W.Y.Wang
Institute of Electronics, Academia Sinica

ABSTRACT ---- A numerical method has been developed for calculating the current distribution on a bicone-cylinder antenna of a EMP simulator and the EM field radiated in free space. The simulator is excited by a pulse voltage.

The antenna is depicted in Fig. and has been excited by a pulse $V(t)=Z\sum a_i \exp(-s_i t)$ where a_i and s_i are complex. Before the current pulse arrived ι , the current distribution was $J(\bar{r},t)=V(t')/2\pi r_o Z_o$, the same as that when the antenna is a infinite bicone, where $t'=t-R/c$ and Z_o is the impedance of the infinite bicone antenna. The pulse has been changed after it arrived ι and reflection occured. However, it is reasonable to expect that the pulses propagated along the cylinder and reflected towards origin have a slower changed pulse form. Therefore, they can be represented as before formally, but a_i and s_i should be slower changed functions of r and t. By appropriate boundary condition, we can obtain equations with undetermined coefficients and can be solved by time-domain technique.

The numerical results are presented. In these examples, the rise time of the exciting pulse is 10μs and the time duration calculated is 120 μs. The results indicate that

(1) The waveform of the EM field radiated by the simulator will not be quite changed when the angle θ varies from 25° to 35°. Of course the amplitude will increase as θ or d increases.

(2) The amplitude of the current pulse reflected from ι will not be very large if θ is not more than 35°. Therefore, the waveform of the field will not be distorted appreciably. It depends on the location of the field point. The rise time will be shorter if φ increases.

(3) The fall time of the EM field will be shorter if θ increases or d decreases.

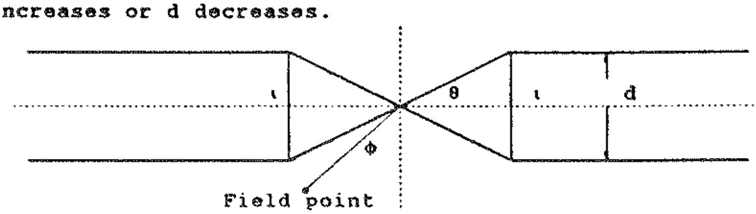

Fig.

CW transfer impedance measurements for NEMP purposes - a comparison of different techniques

C. Goldstein* and P. Mani
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(* on sabbatical leave from Rafael,
P.O. Box 2250, Haifa, Israel)

The transfer impedance of coaxial cables was measured in the frequency range of 200 MHz using the quintaxial, triaxial and stripline injection method. The advantages and disadvantages of the different methods are discussed. Results of far end (forward coupling) and near end (backward coupling) measurements are presented.

A 100 Ω matched triaxial system seems to be the most convenient one for measurements in the above frequency range. It is mechanically simple, the preparation of the CUT is not complicated and it enables both far end and near end measurements. For a 1 m long CUT, phase-difference effects occur in the far end measurements only at frequencies higher than 200 MHz. The matched triaxial method gave also the best results by means of reproducibility.

The quintaxial system is mechanically far more complicated. The preparation of the CUT and the access to it are more difficult. In its conventional structure it does not enable both far end and near end measurements. The main disadvantage of the quintaxial system is that due to its large diameter and complicated structure it is very difficult to match properly at the input and at the output.

Stripline injection is probably the simplest method. Its main advantage is that the velocity of propagation in the inner (cable) and outer (injection) circuits are very close and therefore phase difference effects occur only at very high frequencies. This is not a real advantage if one is concerned only in the frequency range of NEMP. In some cables rather large changes in the measured transfer impedance have been observed when the position of the injection stripline was changed. Also the reproducibility of the measured values was not as good as in the triaxial system.

Pulsed mode transfer impedance measurements of coaxial cables

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(* on sabbatical leave from Rafael,
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Most EMP laboratories possess equipment needed to generate and measure current and voltage pulses, but some lack the instrumentation needed for CW measurements. The pulsed mode measurement of transfer impedance is a more realistic approach since the NEMP is a pulsed phenomena and also because this method enables to inject currents similar in amplitude to the actual currents induced by NEMP.

In the present work direct injection was performed on cable shields using the stripline injection method and indirect injection from an Elgal EM-104 magnetic coupler. The maximum amplitude of the injected current was about 6 kA. A transfer impedance calculated from the ratio of the peak induced voltage and the peak injected current cannot characterize the cable as this ratio will also depend on the shape of the current pulse. The cable can only be characterized by its frequency dependent transfer impedance. This can be obtained from the time domain measurements by Fourier transform. After Fourier transforming, the time domain measurements have been compared with CW transfer impedance measurements in the same cables.

The induced voltage pulse is delayed compared to the shield current, if the transfer impedance is dominated by the diffusion term.

In a magnetically shielded cable hysteresis and saturation effects have been observed. At 6 kA the transfer impedance of this cable increased by an order of magnitude due to saturation.

MEASURED INSERTION LOSS OF AEROSPACE CABLES IN THE 0.5 TO 18 GHZ FREQUENCY RANGE

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Many transients encountered in EMC work have fast risetimes either because the source of the transient has a fast rise time, as in the case of System Generated EMP, or because the transient is clipped by a voltage clamp. Another case of interest is a braided cable with a finite mutual transfer inductance. The mutual inductance will cause the voltage pulse on the center conductor of the cable to.be the differential of the shield current, thus shortening the risetime. An insertion loss that increases with frequency will affect the risetime, and therefore the peak amplitude, of the transients that are transmitted to the electronic circuits that must be protected. If the interference is a signal in the microwave frequency range, the insertion loss attenuates the transmitted signal. The present study measures the insertion loss of generic aerospace cables in order to be able to define the significance of the loss mechanisms.

Standard theoretical treatments of losses in transmission lines (cables) predict that the insertion loss consists of two terms: at low frequencies the insertion loss per unit length is proportional to the cables resistance per unit length while at high frequencies the insertion loss per unit length is proportional to the conductivity of the dielectric surrounding the cable conductors. The frequency dependence of the insertion loss results from the frequency dependence of these two parameters. Below a MHz, the only significant loss mechanism is the d.c. resistance of the cable which is independent of frequency. At some frequency, usually about a MHz, the resistance starts to increase with the square root of frequency because the current no longer diffuses entirely through the cable conductors, but is restricted to the surface of the conductors due to the skin depth effect. Eventually, at some higher frequency, the losses in the dielectric (which are usually proportional to frequency) become the dominant loss mechanism. While the cable geometry and conductor conductivity may be used to predict the skin depth transition frequency, the conductor resistance to dielectric conductivity transition is more difficult to predict because of the lack of conductivity data at the higher frequencies. In addition, the complex geometry of practical cables is expected to introduce additional losses due to multiple reflections and the existence of non-TEM modes. Experimental measurements can be used to define some of these parameters and thus help to understand the propagation of fast rise time electrical transients.

The insertion and return loss of 1 m lengths of a variety of coaxial and twisted shielded pair cable samples was measured using an HP 8408B microwave network analyzer and an S-parameter test set.

The insertion loss of the semi-rigid coaxial Teflon insulated cable sample, with and without holes was proportional to frequency as predicted by a simple dielectric loss model, except at spot frequencies related to the spacing between the holes, the insertion loss is . At the spot frequencies the electromagnetic energy leaks out of the sample and the insertion loss is greatly increased. Except at these spot frequencies, the insertion loss was low (0.15 dB/m-GHz). The insertion loss was also measured for double shielded cable (RG-223), single shielded cable (RG-58), a special foam insulated/silver plated cable and various shielded twisted pairs. Up to 10 GHz, the measured insertion loss was proportional to frequency. For coaxial (50 Ω) cable, the insertion loss was small to moderate (0.2 to 0.6 dB/m-GHz) with samples that incorporated foam insulation and silver plated conductors yielding the lowest insertion loss. Shielded twisted pairs had high losses (1.2 to 3 dB/m-GHz) because of their complex geometry. Above 10 GHz, most of the single braid shielded cables exhibited severe losses. The is most likely due to radiation losses through the shield, as was demonstrated for the solid shields with holes.

EFFECTS OF ENVIRONMENTAL TESTING ON THE SURFACE TRANSFER IMPEDANCE/EMP RESPONSE OF CABLE ASSEMBLIES WITH METAL BANDED BRAID TERMINATIONS

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The shielding of an electromagnetically hardened interconnect system must remain effective throughout its lifetime if it is to meet its requirement of protecting the circuitry from the adverse effects of environments such as lightning, EMP and EMI. The braid to backshell termination can be a particularly vulnerable part of an interconnect system if its is not designed and constructed correctly. Modern braid terminations that use metal bands installed with appropriate tooling provide excellent mechanical integrity while also maintaining a repair capability. This paper will describe the effects that mechanical and thermal environmental testing had on the electromagnetic shielding. This testing was meant to simulate the treatment that an interconnect system might receive during its lifetime.

Before environmental testing, the electromagnetic characteristics of each cable assembly appeared to be determined primarily by the characteristics of the 1 m of cable braid that was incorporated into each sample. The surface transfer impedance of the samples that used a banded braid termination decreased (improved) slightly through the duration of the environmental testing, and the EMP response improved slightly. Environmental testing affected the samples that used the Metcal solder strap braid termination in a manner similar to that observed in the group terminated with the mechanically applied termination band. None of the samples showed significant changes in the high-frequency characteristics (transfer impedance at 10 MHz and maximum transfer impedance) as a result of environmental testing.

EFFECTS OF INITIATION DETAILS ON LIGHTNING RADIATED FIELDS

Robert L. Gardner
Mission Research Corp.
Albuquerque, NM 87106

As a stepped leader nears the ground, an upward going streamer rises to meet it. When the two meet, the return stroke begins, radiating electromagnetic fields. Most of the high frequency emissions of the return stroke are generated at this initiation point; high frequency currents die out in the lossy transmission line formed by the leader channel.

In this paper, a nonlinear nonuniform transmission line model is used to track the currents as they evolve from the initial charged line to the fully developed upward propagating return stroke current. Each element of the transmission line represents a cross section of the channel. This cross section in turn is modeled by a simple three layer hydrodynamic model of the expanding lossy channel. The diameter of the hot channel is allowed to expand as it is ohmically heated changing the inductance, capacitance and resistance of the transmission-line element.

These currents then radiate electromagnetic fields, which may be measured at some distance from the lightning strike. It would be useful to be able to remotely sense characteristics of the return stroke. These calculations predict how joining the upward and downward propagating leaders create the high frequency fields. Variables that are changed include the type of transition from charged to grounded line and length of the transition.

SCATTERING OF AN ELECTROMAGNETIC PLANE WAVE FROM A LOSSY HALF-SPACE IN THE TIME DOMAIN, USING THE INVERSE LAPLACE TRANSFORM ANALYTICALLY

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The one-dimensional electromagnetic scattering problem of a lossy half-space will be considered (plane wave excitation). The usual (and well known) method for obtaining the time domain response in such a configuration is to compute the frequency response for a number of frequencies and apply an inverse Fast Fourier Transform (FFT) numerically.

In this presentation exact analytical time domain expressions will be presented for the reflected and transmitted electromagnetic waves for incident fields with different wave shapes.

These time domain expressions are obtained in the following manner. First, the inverse Laplace transform is applied to the Laplace domain expressions for the reflected and transmitted electromagnetic waves, where the wave shape of the incident field is taken as a delta function. The then obtained impulse response is in closed form, i.e. is given in terms of elementary functions and integrals of elementary functions. Using the convolution theorem the electromagnetic waves for any incident wave shape can then, in principle, be determined. It will also be shown, that if the wave shape $f(t-\tau)$ of the incident field can be rewritten as a product of two functions each of which is dependent on t or τ only, the convolution can be computed very easily by recursively marching on in time. This is because the dependence on t of the integrand of the convolution integral can then be taken outside the integral sign.

To illustrate the above outlined procedure results are presented for incident fields with different wave shapes, a.o. an EMP wave shape. Also some properties of the scattered waves are highlighted.

ON THE TIME-DOMAIN TRANSIENT ELECTRIC FIELD* REFLECTED FROM A FINITELY CONDUCTING EARTH

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Most calculations of the earth reflected electromagnetic fields are performed in the frequency domain and the results transformed numerically to the time-domain by the use of an Inverse Fourier transform. For time domain coupling programs, it would be convenient to have an analytical approach to calculate the reflected fields and avoid the often cumbersome numerical Inverse Fourier transform process. In this paper, an analytical expression for the electric field is derived and compared with numerically calculated values for the case of a transient plane wave reflected from a finitely conducting earth. The plane wave is assumed to have its magnetic field parallel to the earth. The accuracy of the new method is discussed.

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Evaluation of Enhanced HEMP Effects

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This report summarizes an evaluation of enhanced high-altitude electromagnetic pulse (EHEMP) effects on Army systems. An EHEMP is characterized by a larger amplitude, a faster risetime, and a shorter pulse width than previous HEMP threat specifications. The HEMP survivability/vulnerability (S/V) assessment process can be applied to hardened or unhardened systems, and conclusions are generally based on worst-case responses to a specific HEMP threat environment. An EHEMP threat specification may affect both the conclusions of previous S/V assessments and the application of existing assessment and hardening technology to Army systems. Comparisons are presented for generic HEMP and EHEMP waveforms which indicate that in some cases the EHEMP coupling effects are not significant. Also discussed are the typical features of Army systems that may exhibit larger induced transients for an EHEMP than previous HEMP threat specifications.

Shielding Effectiveness Database[†]

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Previous USACERL studies indicate that the measured electromagnetic (EM) shielding effectiveness of a material tested in a 2 foot by 4 foot test aperture is consistently greater than the measured shielding effectiveness of a room, or module, constructed entirely of the material.[1,2,3] Additionally, the measured aperture shielding effectiveness is generally greater than the theoretical while the shielding effectiveness of the module is generally less than the theoretical.

The objective of this project was to establish an EM shielding effectiveness database which would relate the measured aperture shielding to the measured module shielding. Thus one would be able to more accurately predict the shielding effectiveness of a module constructed from a material based on the aperture shielding effectiveness.

Simulated tactical shelters were fabricated from several materials and the shielding effectiveness of the modules were measured using the proposed revision to IEEE-299. The reference materials were chosen so as produce shielding effectiveness values ranging from about 30dB to about 60dB when measured at 150kHz by the low impedance method.

Also included in the database were the shielding effectiveness of the materials as measured in the test aperture and as computed from Schelkunoff's shielding theory.

[†] Project sponsored by U.S. Army Natick RD&E Center.

[1] P. H. Nielsen, *Electromagnetic Shielding Tests on a Room Shielded With Foil-Faced Foam Board*, Technical Report M-86/19, (USACERL, September 1986).

[2] P. F. Williams, K. K. Heyen and R. G. McCormack, *Low Cost Electromagnetic Shielding Using Drywall Composites: Results of RFI Testing of Shielding Effectiveness*, Technical Report M-88/02, (USACERL, October 1987).

[3] C. A. Feickert and W. J. Croisant, *Investigation of Flexible Electromagnetic Interference (EMI) Shielding for the Seams of Expandable Tactical Shelters*, Technical Report M-88/10, (USACERL, April 1988).

RESEARCH AND DEVELOPMENT NEEDED TO MEET NAVAL AIRCRAFT ELECTROMAGNETIC PULSE AND LIGHTNING TEST AND EVALUATION IN THE 1990's

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ABSTRACT

The Naval Air Test Center (NAVAIRTESTCEN) is the Department of Defense's (DoD) only single site laboratory for Aircraft Electromagnetic Environmental Effects (E^3) Test Evaluation (T&E). As a T&E center, we are keenly aware of the importance of Research and Development (R&D) as the foundation for applied technologies. We also recognize that all test facilities have specific missions and accordingly develop test capabilities and methodologies unique to their needs. At the NAVAIRTESTCEN, we have synergized the Nuclear Electromagnetic Pulse and lightning areas and integrated them into the larger E^3 RDT&E arena. This practical approach has reduced test cost and time, and increased the fidelity of aircraft characterization to the general RF environment. Although our capabilities and approach are unique to requirements, they are applicable to the Nuclear Electomagnetic Pulse and Lightning community at large. We have found that even with the benefit of state-of-the-art systems; incorporating methodologies, the job of T&E is becoming increasingly difficult. The benefit derived from modern test technologies has been offset by both a changing threat (DoD-STD-2169/DoD-STD-1795) and rapidly changing aircraft technologies. The specific R&D areas which require continued development include:

- Threat level simulation
  - System (STRESS)
  - Subsystem (STRENGTH)
- Low level system characterization
- Data acquisition and processing
- Modeling and analysis
- Test methologies

As primarily a T&E center, the NAVAIRTESTCEN requires others to develop new technologies to demonstrate feasibly and methology before they are applied in a routine and pragmatic manner.

A CASE FOR STANDARDIZATION OF EMP HARDENING TERMINOLOGY

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Examination of the various handbooks and major reference documents which have been developed over the last few years to provide guidance to those engaged in EMP hardening program reveals a variety of confusing and sometimes conflicting methods (terminology) for describing recommended hardening procedures (not to mention the hardening procedures themselves). A good example is the terminology used for discussing shielding, where terms such as topological, topographical, integrel, tailored, two-level barrier, double tier approach and others including their various subtopics are used interchangeably not only in complementory documents but sometimes within the same document. Other examples are in the areas of terminal protection techniques where we have ESAs vs TPDs vs linear and non linear devices vs filters vs spark gaps, gas tubes, zener diodes, varisters, MOVs etc., and penetration control where we have POEs vs apertures vs penetrations etc.

The purpose of this paper is to present specific examples of the current uses of confusing terminology and provide some recommendations for a standardized set of nomenclature and terms for use in discussing the various aspects of hardening technology.

DEVELOPMENT OF LIGHTNING RESEARCH, DEVELOPMENT, TEST EVALUATION CAPABILITIES FOR DEPARTMENT OF DEFENSE USE

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ABSTRACT

The Naval Air Test Center (NAVAIRTESTCEN) has been tasked by the Office of the Secretary of Defense to develop a DoD Lightning Research, Development, Test & Evaluation (RDT&D) Development Plan. The plan will address the requirements necessary to ensure a continued DoD RDT&E capability in lightning and atmospheric hazards. Specifically the NAVAIRTESTCEN has been tasked to coordinate with representatives of the tri-services to:

- Review current RDT&E capabilities
- Determine systems requiring RDT&E
- Determine general RDT&E requirements
- Review current trends in design and technology
- Make specific recommendations to ensure adequate Lightning RDT&E capabilities

This presentation will provide a general overview of the plan as well as some specific recommendations.

AN INDIAN VIEW OF NUCLEAR ELECTROMAGNETIC PULSE PROTECTION POLICY

*G.K. DEB

Abstract

This paper deals with the Nuclear Electromagnetic Pulse (NEMP) threat analysis, field protection concepts, principles of EMP testing for a realistic nuclear scenario in the context of INDIA's overall weapon strategy. This paper is a short presentation on some of the general principles of a near surface nuclear burst typically of 20 Kiloton (KT) nuclear fission bomb and a high altitude explosion of 1 Megaton (MT) which generates Electromagnetic Pulse on a wider area. The paper also discusses NEMP simulation facilities and various testing conditions that are available in the country. It is well understood that the EMP simulation facility for testing vital and essential hardened systems and to ensure continuous maintenance of these systems should be established on a wider scale in the country for mere survival. The paper discusses in details some of the NEMP protection measures that are generally applied to ground based systems and the general awareness of the EMP Science and Engineering in INDIA.

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Design of INSIEME
Bounded Wave EMP Simulator in Italy

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ABSTRACT

Impianto Nazionale per la Simulazione di Impulsi Electro-Magnetici Esoatmosferici is a conical transmission type EMP simulator being designed to be built at CRESAM, near Pisa in Italy. In this paper we will describe the Electromagnetic design aspect in INSIEME. This simulator has 100 Ω TEM mode characteristic impedance and will be excited by a 1.3 MV, 5 nanosecond risetime pulse generator. Some aspect of Electromechanical engineering design of the simulator including the termination will be discussed. In addition, the expected Electromagnetic performance in terms of impedance and field uniformity will be presented.

VEPES-SWISS EMP SIMULATOR DESIGN AND PERFORMANCE

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VEPES - Vertically Polarized EMP Simulator, was recently installed at the NC Lab in Switzerland. Initial measurements of the electric and magnetic fields were performed in the working volume. The simulator is a bounded wave type simulator composed of mesh plates at an angle of 11°, excited by a fast 1MV generator on one side and terminated with a distributed termination on the other side. The antenna impedance is 90 Ω. The peaking network is based on a fast peaking capacitor and a low inductance variable-gap main switch. A unique feature of the simulator is the interface pulser-antenna which employs insulated transmission line rods rather than volume insulation of the interface. The interface design, along with the peaking network allows rise-times of <5 ns. The interface is designed to match the 90 Ω impedance of the antenna. The simulator design features, computer calculations of pulser output and field distribution in the interface along with field neasurements will be presented.

EMP SIMULATORS A HEALTH HAZARD? MEASUREMENT RESULTS FROM THE SWISS EMP SIMULATOR MEMPS

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ABSTRACT

Recently it has been reported elsewhere that there might be a correlation between the occurrence of rare cancers and working with EMP simulators. High-voltage pulsed-power EMP simulators accelerate charge which has then the opportunity to interact with both high-Z and low-Z materials inside the simulator. In order to check this potential possibility of X-ray generation in the Swiss mobile EMP simulators (MEMPS) measurements have been performed.

During a test period of 18 days several film badges as usually employed to monitor the radiation dose of people working in areas where ionizing radiation is expected to have been attached to the outside of the pulser. The MEMPS is a 4 MV electromagnetic pulse generator used to test the EMP hardness of electronic equipment. During the above mentioned test period a total of 250 pulses of different output voltages up to a maximum of 3.5 MV have been generated.

The dosimeters were of the type TLD-700 with a lower sensitivity level of about 8 mrem and an inaccuracy of + 30%. The film badges have been analyzed and background subtractions have been made. This paper discusses the results of these measurements.

ELECTROMAGNETIC PULSE AND LIGHTNING SIMULATORS AT THE NAVAL AIR TEST CENTER

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ABSTRACT

The Department of Defense (DoD) has required though a series of DoD directives that all military services address weapon system survivability, reliability, and maintainability in the same vain as operational design considerations. In support of the acquisition of survivable systems, the Program Managers have the burden of instituting requirements and planning for, and implementing their programs to demonstrate survivability throughout the weapon system acquisition and service cycle. To support the Program Managers in their Nuclear Survivability Electromagnetic Pulse and Lightning hardening and survivability Test and Evaluation (T&E) programs, the Naval Air Test Center (NAVAIRTESTCEN) has developed a state-of-the-art capability for testing Navy and other DoD systems. A significant element of this capability are the NAVAIRTESTCEN NEMP and Lightning simulators. The available NAVAIRTESTCEN simulators cover a broad spectrum of EM environment simulation.

The NAVAIRTESTCEN is the DoD's only "single site center" for aircraft Electromagnetic Effects (E^3) T&E. As an element of the T&E center, the synergistic Nuclear Electromagnetic Pulse and Lightning areas, which are the subject of this presentation, have been integrated into the larger E^3 RDT&E arena providing complete "one stop shopping" E^3 (EMP, Lightning, EMI/EMC, EMCON, Tempest, HPM, P-Static) test capability. This practical approach has the potential of reduced test cost and time, and increased the fidelity of aircraft test and evaluation to the broad spectrum of EM environments whether for weapon system survivability/vulnerability assessment, design verification, or reliability/maintainability support testing. Although the NAVAIRTESTCEN test capability evolved largely in support of Naval systems T&E requirements, it is applicable to the Nuclear Electromagnetic Pulse and Lightning community at large. The NAVAIRTESTCEN, as a Major Range Test Facility Base (MRTFB), provides state-of-the-art simulation capability with major advancements incorporated over the last three years.

MECHANISMS FOR THE SPLITTING OF DEGENERATE NATURAL FREQUENCIES IN COUPLED MULTICONDUCTORS

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Natural frequencies of strongly coupled wires do not only experience a shift from their unperturbed values but also experience splitting. There are various physical mechanisms associated with frequency splitting. In our contribution we (among others) study the influence of losses on cables, distance variations between cables and different geometries of cables on the natural frequencies. It is shown that a high symmetry of the considered configuration is accompanied by a high degree of degeneration. The above mentioned influences on cables in general imply resolution of degenerate natural modes. Theoretical analysis of these phenomena is performed in the framework of transmission line theory applying perturbation theory and group-theoretical - as well as algebraic - considerations. Some selected simple experiments are reported which confirm our analytical analysis.

*On leave of absence from the NBC Defense Research and Development Institute, D-3042 Munster, Federal Republic of Germany.

ON THE INCLUSION OF LOSS IN TIME-DOMAIN SOLUTIONS OF FIELD-TO-TRANSMISSION LINE COUPLING

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ABSTRACT

Time-domain solutions of field-to-transmission lines coupling give the possibility to take into account non-linear phenomena, as for instance the operation of over-voltage protection. As a result the use of this method has become more and more attractive compared to the frequency-domain approach. The main problem remains however to find a suitable way of taking into account frequency dependent phenomena such as the skin effect.

Different authors have proposed approaches to include the frequency dependent parameters into time-domain solutions, using the convolution techniques[1,2]. Applying these techniques to the expression of the ground impedance a convolution integral appears in the time-domain equation describing the field-to-transmission line coupling phenomena. A method for avoiding the singularity of the integral at t=0 and for solving the coupling equation is proposed using the point-centered finite difference technique. This method has been applied to compute the effect of an EMP on an aerial line over a finite conductive soil.

Comparison with results obtained by using a fixed-frequency ground impedance value have been performed. The comparison shows that it is possible to find a particular frequency for which the response of the line to the EMP is very similar to the computation performed taking into account the frequency variation of the ground impedance.

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[1] W. Scott Meyer, H. W. Dommel, "Numerical Modelling of Frequency-Dependant Transmission-Line Parameters in an Electromagnetic Transients Program, IEEE Trans. on PAS, pp 1401-1409, 1974.
[2] F. M. Tesche, "On the Inclusion of Loss in Time-Domain Solutions of Electromagnetic Interaction Problems", Nov. 15, 1988.

WAVEGUIDE MODEL OF MULTICONDUCTOR TRANSMISSION SYSTEM WITH RESISTIVE LOADING

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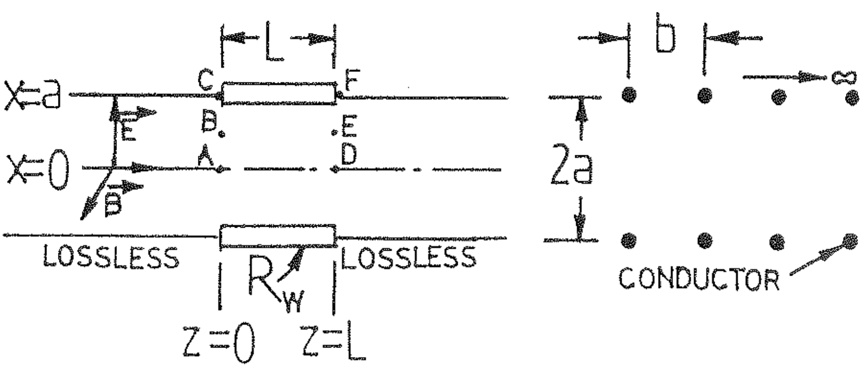
In this study we examine the two-dimensional space-time behavior of the electric and magnetic fields as a function of wall resistance for a multiconductor transmission system as shown in Fig. 1. For this configuration the effective wall resistance is given by $Z_w = R_w b$, where R_w is the resistance per unit length for a single conductor and b is the transverse separation between conductors.

The physical model of Fig. 1 lends itself to an exact analytical solution using a waveguide model. The fields in the resistively loaded region are expressed as a sum of modes. We have found that five modes are sufficient to adequately define the fields.

In the model of Fig. 1 a TEM wave enters the resistively loaded region at z = 0 and emerges from z = L with a reduced vertical component E_x because of wall losses. As the ratio Z_w/Z_0 increases the ratio $E_x(x=a)/E_x(x=0)$ decreases, and the character of the wave begins to differ significantly from the original TEM wave owing to the generation of a strong E_z component. This component is necessary to support the wall losses.

Numerical results for the fields at positions denoted by A, B, C, D, E, and F in Fig. 1 are presented which show the distortion of the field as a function of wall resistance. The limitations of representing this type of system by ordinary transmission line equations are discussed.



(a) Side View

(b) End View

Figure 1. Multiconductor Transmission System

AN EVALUATION OF THE I_B TO I_W METHOD OF DATA ANALYSIS

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ABSTRACT

To date, there are no standardized rules for extending bulk cable current measurements (I_B) to the associated cable wire. Standardization of this type of analysis method contributes to efficient and cost effective weapon system EMP assessment programs.

This paper presents a summary of a recent I_B/I_W ratio study. The study compiled 778 I_B/I_W ratios derived from EMP response data acquired during three H-60 helicopters (SH-60B, VH-60, and UH-60A) EMP test programs. These H-60 I_B/I_W results were compared to previous I_B/I_W work performed for four fixed wing aircraft, and to an analytically derived I_B/I_W predictor. This study differs from previous related work in this area in that it is based on data acquired from largely composite systems. Also, previous studies have adressed primarily fixed-wing fighter and command, control, and communications (C^3) aircraft.

Data presented in this paper are based on the "Technology Advancement Interim Report, I_B To I_W Method Of Data Analysis Evaluation", BDM-ABQ-90-0008-TR.

This work was sponsored by the Defense Nuclear Agency (DNA/NMRS), Kirtland AFB, NM. This presentation is unclassified.

NUMERICAL ANALYSIS OF THE HARDNESS SURVEILLANCE ILLUMINATOR

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A rhombic wire configuration (called the Hardness Surveillance Illuminator-HSI) has been developed for providing CW illumination of large electrical systems. The design which is based upon transmission line considerations has shown to perform well up to 100 MHz. A study of the performance for frequencies up to 500 MHz is presented.

The high frequency analysis is accomplished by the application of numerical techniques. Specifically, the NEC-2 program with minor alterations is used to compute the wire currents and the field configuration that is developed in the working volume of the illuminator. Within the HSI facility are regions of ground screen, wire radials, concrete, and dry soil. All of these regions are considered in the model.

At low frequencies near 10 MHz and below the wire configuration acts like a waveguide. As the frequency approaches 100 MHz the working volume is illuminated by radiation. Within the concrete and soil regions the ground losses significantly perturb the principle field components. Computations indicate that the HSI facility may be operated for frequencies up to 500 MHz. A determination of the performance above 500 MHz requires a new analysis technique.

Broadband Properties of the Two-wire Hardness Surveillance Illuminator (HSI)

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Abstract

The characteristics of the HSI are illustrated, with particular reference to its performances at high frequencies, i.e. beyond 100 MHz. An approach is presented to calculate the currents and fields approximately, based on an asymptotic antenna theory. This offers an improvement over the transmission line model, and allows the prediction of fields at higher frequencies. Some comparisons are made between calculations and existing field-map data.

A STUDY OF THE EM FIELD ENVIRONMENT IN THE VICINITY OF A CW RADIATOR

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ABSTRACT

The use of CW testing is sometimes used for EMP hardness assessments in lieu of threat-level pulse testing. Frequently, this involves locating an impedance loaded antenna in close proximity to the system being tested and exciting the antenna with a swept or stepped CW signal from sub-megahertz frequencies to 100 megahertz, or so. The measured CW system responses thus obtained are then manipulated mathematically to permit the estimation of the expected plane wave, transient responses.

A key element in this process is the knowledge of the EM field environments in the vicinity of the radiator. Both spatial and frequency variations are of interest in this regard. This paper describes the analysis of a typical CW radiator using a rigorous model of an antenna over a lossy earth. The antenna solution is determined using the moment method, formulated with the Sommerfeld representation of the lossy earth. Variations of the EM fields in the vicinity of the antenna are studied, and plots of the frequency behavior of the fields at selected points are presented. The reconstructed transient fields from this simulator are also explored.

This work has been supported by the Swedish Telecom, under the TEMPERATUR Program.

Field Characteristics of A Thin-wire EMP Simulator of Semi Elliptical Geometry

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Abstract

An approximate solution for the current of a thin elliptical loop has been determined, based on an asymptotic antenna theory. The fields at and around the center have been calculated, to illustrate the broadband behavior of this structure when used as an EMP simulator. The criteria for choosing a uniform loading resistance to control the field behavior at low frequencies are illustrated. A comparison is presented between fields calculated and measured in an actual EMP simulator.

PERFORMANCE OF FOUR-WIRE ANTENNA IN ANECHOIC CHAMBER

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ABSTRACT

The design and implementation of a so-called VV antenna for broadband anechoic chamber illumination is presented. The antenna is a free space version of Hardness Surveylance Illumination (HSI), but of much smaller scale. The VV antenna has been installed in the University of Michigan tapered anechoic chamber whose dimensions are 18 meters in length and 5.4 meters in width and height at the working end. At present, the antenna is configured for vertical polarization and is fed from ultra-broad ballun followed by a pair of matched amplifiers, one in each (differential) side. This antenna has been analyzed using numerical analytical techniques. Here we present comparision between theoretical and measured values of parameters such as input impedance, efficiency, frequency response, and field uniformity.

Sample surface current measurements are presented for a sphere, and a B-1B model aircraft in free-flight and refueling mode configurations to demonstrate the capability of the facility.

Currents on a Wire in Aperture Coupled Cavities

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An incident plane wave is coupled to a wire placed inside a cylindrical cavity of rectangular or circular cross section. The coupling is done through an aperture in one wall of the cavity. The current on the wire is the solution by means of a moment method of an integral equation obtained from a dyadic Green's function integral representation of the field inside the cavity. Over the frequency range 100MHz to 5GHz the equïvalent dipole approximation used to model the aperture leads to acceptable results for the current.

Some numerical problems related to the computation of the dyadics Green's functions and to the application of the method of moments in that particular case will be discussed. The currents on loaded/unloaded wires are computed as a function of :

1) the incident wave: angle of incidence,frequency,polarisation,
2) the aperture parameters: dimensions, orientation, location on different walls of the cavity,
3) the position of the wire inside the cavity.

The influence of the geometry of the cavity will be emphasized through a comparative study of currents in both cases and in the one of a wire in free space. This part of the investigation is done with the aim of finding some approximate and still accurate form of the solution in order to avoid lengthy computational times and obtain somme physical insight into the coupling phenomena.

SCATTERING PARAMETERS OF E.M. COUPLING THROUGH AN APERTURE

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The aim of the paper is to express the coupling of two wires located both sides of an aperture in a conducting plane in the formalism of the Electromagnetic Topology.

The scattering parameters of the experimental device are determined considering four points taken at the extremities of each wire. Therefore, we define an electrical model where the coupling through the aperture is represented by a current and a voltage generators, according the K.S.H. Lee's representation. Furthermore we propose an analytical expression of the scattering parameters in the quasi-static approximation.

The analysis of the experimental curves representing the energy transferred from a volume to the other gives the equivalent voltage and current sources. The results are compared to a well-known analytical expression in the case of large apertures.

The B.L.T. equation is then used to determine the scattering parameters of the junction located at the aperture level: they are in fact the parameters of the aperture.

We'll show how these results can be integrated in the "Good-Shielding-Approximation".

HIGH FREQUENCY ELECTROMAGNETIC COUPLING THROUGH SLOTS AND RIVETED SEAMS

by

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ABSTRACT

The coupling of high frequency (microwave) electromagnetic radiation through slots and riveted slams in infinite metal sheets is investigated using a combination of time domain finite difference techniques and the analytic expressions for the fields due to sources in an aperture in a plane sheet, first derived by Smythe*. The aperture sources are calculated using time domain finite difference transient excitation of the aperture. The source fields are then transformed to the frequency domain and applied to the analytic expressions via numerical integration over the aperture to obtain the transmitted and backscattered electromagnetic fields. Results for rectangular slots show large transmitted fields at the slot half wave resonance and its odd harmonics, for the excitations studied. The transmitted fields for the riveted seam are large at frequencies corresponding to a skin-support member overlap resonance and a rivet separation resonance.

*W.R. Smythe, Phys. Rev. 72, 1066 (1947)

ELECTROMAGNETIC PROPERTIES OF JOINTS BETWEEN METALLIC AND COMPOSITE SURFACES

by G. Labaune, M. Sternberg, V. Gobin, J. Grando, J.C. Alliot

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oints are an important way of electromagnetic energy penetration nside aircraft.

ne junction between metallic structures and finite conductivity panels as been studied theoretically by Casey in the case of circular panel f isotropic and finite conductivity surrounded by uniform resistive oints.

e present a study of the diffraction of the magnetic field through an perture loaded by a finite conductivity material. The panel onductivity may be isotropic or not and the joint conductivity may be niform or not.

ne experiment was carried out with a T.E.M. cell allowing the easurements of the magnetic field diffracted through a panel rradiated by a plane wave.

he numerical calculation uses the moments method to solve the EFIE quation.

e present a comparison between experimental and numerical results hich show a large influence of the joint resistance distribution in he case of a nonisotropic conductivity of the panel material.

DESCRIPTION OF A NEW SURFACE IMPEDANCE SENSOR FOR CONDUCTIVE MATERIALS

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Usually, the method to measure the surface impedance of a conductive material consists to measure the shielding effectiveness of a sample of this material interposed between a radiating antenna and a receiving antenna. This method has some drawbacks:

- the measurements depend upon the geometry of the sample and upon the electrical connection between the sample and the surrounding structure. Thus, the relation between shielding effectiveness and the material conductivity has to be calculated. An analytical calculation is possible in a few cases (for exemple, a circular aperture in an infinite conductive plane loaded by conductive material and irradiated by a plane wave),

- the measurements must be carried out both sides of the sample. This drawback is very important for practical uses.

We show, using an analytical calculation, that we can use a particular irradiation of the sample which allows to avoid these two drawbacks.

Theoretical results are compared to experimental results for samples which surface impedance varies from some micro-ohms to several ohms. This measurement method leads to the definition of a sensor. This one allows to measure the conductivity of conductive materials. The samples may be of any shape, connected or not to any structure. They can be covered by insulating coating and the measurement is carried out using radiating and receiving antennas located only one side of the sample.

RESPONSE OF AN OVERHEAD WIRE NEAR A NEMP SIMULATOR

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ABSTRACT

The response of an overhead wire illuminated by a simulated nuclear electromagnetic pulse (NEMP) has been experimentally investigated. The wire is 70 m long, 7 mm in diameter and is situated 5 m above ground. It is located 20 m away from a hybrid type of EMP simulator. The simulator is a resistively loaded elliptical loop structure with its pulse source located 20 m above the ground. The overhead wire is terminated with various combinations of short circuit, open circuit and characteristic impedance at the two ends and the current response is measured at one end and in the middle. The measured responses are compared with calculated values from available analytical models.

The authors wish to thank the Swiss Armament Technology and Procurement Group, Spiez (Swiss Department of Defense) and the Swiss Federal Railway Company for their support and cooperation.

A GEOMETRY DEPENDENT CAR MODEL DERIVED FROM A TWO-DIMENSIONAL SURFACE LAPLACIAN

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For a thin conducting surface, the two dimensional Laplacian solution can be applied to the surfaces of three-dimensional configurations. A resistive sheet solution resulting from "unfolding" the three-dimensional structure has been applied to two basic geometries. A rectangular parallelepiped and a right circular cylinder are used to approximate the principle structures of a generic railroad boxcar and tank car. From the numeric solution of the Laplacian, inferences concerning the low frequency (static/quasistatic) response can be made for these geometry dependent structures due to a DC (or near DC) current flow into and out of the cars. The interior diffused H-fields, surface current density contours, streamlines, resistance, self and mutual inductance are presented for these railcar-like geometries.

Broadband Strength Testing

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The adoption and subsequent refinement of MIL-STD-461/462 has been a significant step forward in the arena of specifications and standards. Baseline strengths for aircraft LRUs can be determined empirically using at least 5 different damped sine waveforms with varying frequency and amplitude. Even though provisions exist in the conducted susceptibility portions of MIL-STD-461/462 to test at other than the basic 5 frequencies of 10kHz, 100kHz, 1 MHz, 10MHz and 50 MHz when warranted by system design considerations, using a test waveform specification with more of a broadband character would tend to assure that the strength of a system had been tested over the entire frequency band of interest.

With the advent of technological advances such as Arbitrary Waveform Generators and pulse amplifiers, more complex waveforms can be used for LRU strength testing. This paper will address three issues associated with the general used of broadband strength testing:

- appropriate replacement strength waveforms which ensure at least MIL-STD-461/462 LRU strengths
- potential basis functions derived from actual EMPTAC EMP data which could be used for general LRU strength criteria
- the need for careful attention to signal/noise issues when using broadband strength verification methods in assessment programs

HPM weapons: fantasy, or frightening reality?

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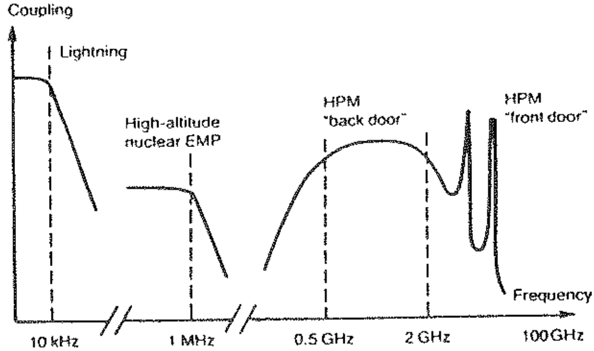
This paper is based on a report originally prepared for the Swedish Military Information conference 1989, MILINF 89.

It discusses High-Power Electromagnetic Weapons becoming part of electronic warfare, comparison of electromagnetic threats, advantages and disadvantages of HPM weapons and some remarks on the HPM program in Sweden.



Electromagnetic threats from lightning, high-altitude nuclear EMP, and high-power microwave coupling as a function of frequency (schematic diagram).

COMBINING RF SOURCES USING C_N SYMMETRY

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This paper considers the use of point symmetry groups (rotation and reflection) for designing arrays of RF sources. Symmetry is helpful for operating all the sources under the same conditions of voltage, current, etc. Besides having the sources, all operate at the same frequency one needs to control the relative phases so that the signals can be appropriately added.

SLOWER TO FASTER WAVE SOURCES

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This paper presents the design of several multi-section transformers which allow slower waves, such as those found in slow wave structures for travelling wave tubes (TWT's), magnetrons, and some lasers, to become faster waves without the degradation of losing phase and energy. Examples are given for periodic structures with 11 Sections or Unit Cells and 10 Junctions, decreasing monotonously to 2 Sections or Unit Cells and 1 Junction in decrements of 1 Section and 1 Junction. These are portrayed for Bandwidths (BW) of 2.0 (Chebyshev's) and 1.0 (Binomial and Pascal's), where BW is the ratio of the upper frequency to the lower frequency in the band. This method is very versatile because it can be applied to Very Narrow BW of 1.0 to Awful Wide Bandwidths (AWB) of 10.0 and higher. A transformer is presented for AWB of infinity.

* Dr. Biggs is also Professor of Electrical Engineering at the University of Alabama.

LINEAR DISPERSION RELATIONS FOR AXIAL MICROWAVE SOURCES

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We develop a homogeneous linear integrodifferential equation describing the mall-signal behavior of "axial" microwave sources wherein the current is contrained to flow in a fixed direction. The eigenvalues of this integral equation yield he complex frequencies at which small-signal operation is possible, as functions of he beam and structure parameters. The microwave source structure is described by ın appropriate Green's function, whose eigenfunctions play a critical role in shaping he solutions to the integral equation. Because the finite length of the structure is ncluded *ab initio*, the start-oscillation conditions are obtained directly.

Numerical data are presented to illustrate the analysis as applied to a Čerenkov oscillator. Applications to other microwave sources such as backward-wave oscillaors are also discussed.

TECHNIQUES FOR PROPER MEASUREMENTS OF ELECTROMAGNETIC FIELDS

By

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The measurement of electromagnetic fields in free space is not a trivial task. The instrumentation system scatters electromagnetic energy and hence purturbs the measurement. Currents and charges are induced the instrumentation which add unwanted signals to the field sensors. Undesired field components can generate unwanted signals in the sensors unless they have been carefully designed and manufactured. Dynamic range considerations in data transmission links and recording instrumentation are essential to prevent signal saturation or excessive noise on the data.

This paper addresses the sources and solutions of these potential problems, based upon many years of practical experience. Electric and magnetic field sensor designs are discussed, based on Maxwell's equations, which allow for the measurement of a single field component. Alignment of the sensors and auxiliary equipment along equipotential surfaces so as to minimize field scattering and current/charge coupling into the sensors is discussed. The use of common-mode baluns to quantify this unwanted coupling and minimize it is addressed. Also mentioned is the proper design and setup of isolated data links and transient data recorders.

The very important issue of instrumentation setup and checkout is highlighted. Noise shots, sensor inversion, common-mode measurements, etc., are imperative before data are acquired and again periodically during a long test program. Improper instrumentation configuration and checkout are inexcuseable; the cost of bad data is very high.

This work was sponsored by EG&G for clarification of specifications of existing commercial products.

ENHANCED E-FIELD SENSOR FOR LOW FREQUENCY MEASUREMENTS

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Typical time derivative electric field (D-dot) sensors have good high frequency S/N ratios, but have inadequate lower frequency sensitivities for some measurement situations. A project involving the measurement and analysis of the transient electric fields caused by high-voltage switching operations in electric power substations required the acquisition of time-domain field waveforms over a bandwidth ranging from a few Hertz to above 100 MHz. A "slow" antenna capable of capturing the low frequency/late-time "tail" of electric field waveforms was developed by combining a conventional charge amplifier/integrator with a concentric disk dipole D-dot antenna. Normally, the late-time tail is missed due to the tradeoff between the 50-ohm RC integrator's time-constant and the sensor's derivative frequency response. Comparisons between data acquired with a traditional ACD-60 E-field sensor (with a 10uS RC-integrator) and data acquired simultaneously using the slow antenna are presented.

This work is sponsored by the EPRI Electrical Systems Division under contract RP2764-1.

The authors wish to acknowledge W. Reeson and W. P. Winn of N.M.I.M.T. for their suggestions regarding the electronics for this low frequency electric field sensor.

An Incident Field Sensor for EMP Measurements

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When measuring fields at hybrid EMP simulators, it is often desirable to have a sensor that is directional. By this, we mean the sensor has a cardioid, or 1+cos(theta) antenna pattern. This allows one to measure only the incident field in an environment where both incident and reflected fields are present.

With currently available sensors, we are only able to measure total (incident + reflected) fields. There are times, however, when it would be useful to isolate the incident field from the total field. An example of this is when performing extrapolations at hybrid EMP simulators[1], such as ATHAMAS I, also known as HPD. This paper describes the development of a sensor that isolates the incident field from the total field.

The design of the sensor is based on an idea develolped for a unidirectional EMP simulator[2]. By using this device as a receiving antenna instead of a transmitting antenna, a directional sensor is achieved. We call this sensor the Balanced Transmission line wave sensor, or BTW.

In this presentation, a simplified theory of operation is discussed, and experimental results are presented. We found the Front/Back ratio of our prototype sensor was 20-29 dB. This may be adequate for practical applications, and it may be possible to improve the Front/Back ratio with further work.

[1] E. G. Farr, Extrapolation of Ground-Alert Mode Data at Hybrid EMP Simulators, Sensor and Simulation Note 311, July 1988.

[2] J. Yu, et. al., Multipole Radiations: Formulation and Evaluation for Small EMP Simulators, Sensor and Simulation Note 243, July 19, 1978.

COMPARISON OF MEASURED VS. CALCULATED INCIDENT FIELD MEASUREMENTS

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ABSTRACT

The present sensors used to measure the fields at an Horizontally Polarized Dipole (HPD) EMP simulator record the total field. These measurements are a superposition of the incident and reflected fields. Extrapolation functions are based on a ratio of the actual measured incident field and a threat incident field. Therefore it is necessary to obtain the measured incident field. Presently, to obtain the incident field both the electric and magnetic fields must be measured and then mathematically combined to produce an incident field waveform.

Recently, a magnetic incident field sensor was designed and produced by the BDM corporation. This sensor was tested at the Kirtland HPD facility. The data obtained from this sensor are compared to the calculated incident fields measured at the same locations during the EMPTAC Test 4.

An analysis of the peaking circuit

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Peaking circuits are intensively used in pulsed power and EMP simulators when fast risetimes are required. A peaking circuit consists of a peaking capacitor an inductor and a switch. The shape of the pulse is very sensitive to the values of the capacitance, inductance, and the switch firing time.

The proper values needed for a good pulse shape and the effect of a deviation from these values are discussed and demonstrated by means of numerical calculatins.

The charging time constant of the peaking capacitor C_p, through the inductor L, should be approximately equal to the discharge time constant of C_p through the load R.

C_p should be small compared to the generator capacitance C_g, but too small C_p will cause oscillations on the decay and will increase the sensitivity to the switch firing time. The switch should be fired when $V(C_p) \approx V(C_g)$.

A fast risetime small EMP simulator

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During the last few years there has been much talk in the EMP community about weapons which generate an EMP pulse with risetime considerably shorter than the 5 ns required for EMP simulation according to Mil Std 461 c.

In the large multy megavolt simulators, a risetime of 5 ns is about the limit of available technology. In smaller simulators, with dimensions limited to a few meters and which are driven by generators of a few hundred kV, the risetime can be reduced if very carefully designed. The high frequency content of the shorter risetime will couple effectively only to short conductors which occur mainly in small systems or at the subsystem level. A test of small units with a small simulator having a fast risetime might be of great value in the process of testing and hardening.

In the present work an EMP simulator is described for which the measured risetime of the E field, in the working volume, is less than 2 ns. A large part of the measured risetime is contributed by components of the measuring system, such as the E probe, cable and oscilloscope. Eliminating these factors would result in a risetime of $T_r \approx 1.5$ ns.

The simulator consists of an Elgal EM-103 100 kV generator, a peaking circuit and a 1 m high "parallel plate" radiator. A fast and low jitter switch was developed for the peaking circuit. The peaking capacitor is either a flat or coaxial transmission line.

Numerical calculations were performed in order to establish the optimal values of the components in the peaking circuit and the time at which the switch should be fired.

CANONICAL EXAMPLES FOR HIGH-FREQUENCY PROPAGATION ON UNIT CELL OF WAVE-LAUNCHER ARRAY

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This paper extends the available analytic solutions for a periodic array of wave launchers. These solutions are based on the high-frequency approximation of the multiconductor transmission-line equations. The examples here are for some profiles of the characteristic-impedance matrix (2 x 2) for two conductors (plus reference). Comparing the solutions for different profiles one can begin to optimize the profile.

A FAMILY OF CANONICAL EXAMPLES FOR HIGH FREQUENCY PROPAGATION ON UNIT CELL OF WAVE-LAUNCHER ARRAY

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ABSTRACT

Recent papers [1,2 and 3] have considered the high-frequency (or equivalently early-time) propagation of a step pulse source at the apex, along the unit cell of a symmetric in-line , periodic array of wave launchers. Starting from multiconductor transmission line equations specialized to a two conductor (plus reference) model for the unit cell [3] derives an expression for the voltage transfer ratio from the source to the aperture plane in the high frequency limit. Using these available solutions, a family of design curves that permit a desired high-frequency voltage transfer ratio from the input at the apex to the aperture plane are computed and plotted.

References

1. C.E.Baum, Coupled Transmission-Line Model of Periodic Array of Wave Launchers, Sensor and Simulation Note 313, December 1988.
2. D.V.Giri, Impedance Matrix Characterization of an Incremental length of a periodic Array of Wave Launchers, Sensor and Simulation Note 316, April 1989.
3. C.E.Baum, Canonical Examples for High-Frequency Propagation on Unit Cell of Wave-Launcher Array, Sensor and Simulation Note 317, April 1989.

UPGRADING EXISTING EMP SIMULATORS FOR ENHANCED SYSTEM VULNERABILITY ASSESSMENT

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DoD directives for enhanced HEMP weapon system survivability have provided an impetus to assess existing EMP simulator capability and upgrades (designs). The AFSC/WL at Kirtland Air Force Base has investigated several upgrade designs for various EMP simulators. These include the HPD, VPD, TRESTLE, and ALECS R&D facilities. At HPD using the HAG-1A pulser, measurements indicate a (10 to 90 percent) 1.2 ns risetime environment can be provided throughout the working volume. With minor modifications to the HAG-1A risetimes of less than a nanosecond can be expected along with a 50 kV/m peak field amplitude directly underneath the antenna in a half rised configuration.[1] At VPD, a multichannel switch could be used to provide environments in the he 1 and 2 ns range.[2] Results of laboratory experiments will be discussed. A proposed upgrade of the TRESTLE pulse power system would also support launching of short risetime pulses by improving the pulser/switch/transmission line interface.[3] Substantiating measurements acquired during a "point-source" experiment at TRESTLE will be presented.[4] Finally, a conceptual design consisting of a hybridized HPM/EMP ALECS simulator will be discussed.[5]

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[2] "VPD-II Upgrade," BDMMSC/TRE Final Report, Subtask 03-03-00, 303-RTa-88-001, Contract F29601-87-0201, April 19, 1988.

[3] "Engineering Study of TRESTLE Pulse Power System Reconfiguration," BDMMSC/KIR Final Report, 311-RTa-86-002, Subtask 03-11, Contract F29601-82-C-0030, December 22, 1986.

[4] "TRESTLE Point Source Test," BDMMSC/KIR Final Report, Subtask 03-09/01, 309-RTa-86-001, Contract F29601-82-C-0030, May 2, 1986.

[5] "Hybridized EMP/HPM Simulator for High Frequency Susceptibility Testing," published in Conference Proceedings of the Seventh DoD Conference on DEW Vulnerability, Survivability and Effects, U.S. Naval Postgraduate School, May 9-12, 1989.

EXPERIMENTAL PRETEST SURVEY--A NEW TECHNIQUE FOR DETERMINING EMP TEST POINTS

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Test point selection and pretest analysis frequently consumes a large amount of time during EMP test planning because of the many unknowns in the electromagnetic shielding topology of the item under test and uncertainties that naturally exist in the circuit threshold distribution. If the system uses non-linear hardening elements to reduce the coupling via conductive penetrations, additional uncertainties are present. Resolving these uncertainties is time consuming, expensive and frequently impossible. As a result, the test planner will try to cover as many eventualities as possible, specify as many test points as there is money for and hope that all the significant points of entry have been included. Experience has shown that many times significant coupling paths are missed, either because the system has been modified or because the characteristics of the points of entry were now known or understood. This paper shows how several new techniques, such as SPEHS, HSI, and R^2SPG, can be used to guide the test planner towards a successful test.

In the last few years, a number of simple hardness surveillance test technologies, such Single Point Excitation for Hardness Surveillance (SPEHS) and the Hardness Surveillance Illuminator (HSI), have been developed which allow the outer shielding topology to be quickly characterized. For an experimental pretest survey, the SPEHS or HSI techniques are used to excite the aircraft at its fundamental resonant frequency (usually a few MHz) and sometimes at a few spot frequencies in the 10 to 100 MHz frequency range. These excitation techniques require a minimum of facilities, therefore, techniques like SPEHS can be used where the aircraft are rather than where the EMP facilities are. A battery operated field strength meter and appropriate sensor is used to map the fields on the exterior surface of the aircraft and at the proposed test point locations inside the aircraft. Ratios of these fields give a first cut of the the transfer functions that characterize the shielding topology. Using a current probe instead of an antenna on the field strength meter allows the conductive penetrations to be characterized and field to cable current transfer functions to be obtained. Using the field strength meter as a "sniffer" allows the electromagnetic "hot spots" to be located and identified.

The electrical strength of the system can be determined using the Random Repetitive Square Wave Pulse Generator (R^2SPG) technique. This technique injects thousands of pulses onto the aircraft's cables in a controlled fashion. Although it is small, simple and battery operated, it can inject damped square waves onto the cables with currents up to 16 A. The interval between pulses is random with an average repetition rate of 30 Hz. This technique allows the upset threshold to be determined using currents that are usually equivalent to those expected by the threat plus a safety margin. A first cut of the upset vulnerability can usually be performed in a few days.

By investing a few days in an experimental pretest survey, the test planner gets a set of transfer functions that allows test point selection to be performed with increased confidence. In addition, the crude estimate of the hardness obtained during the pretest survey allows the planner to estimate if the system has the necessary hardness to make a full EMP test worthwhile, or if certain elements of the system should be modified prior to test.

FAULT INSERTION TESTING
A METHOD TO DEMONSTRATE SYSTEM LEVEL EMP SAFETY MARGINS

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System-level EMP tests are performed to characterize the hardness of complex weapons systems. These tests usually focus on collecting data to validate specifications and allocations. In addition, they often include a "Generals test" to demonstrate that the weapon system operates through a full level EMP without mission degradation (upset). However, rarely do these tests give margin information; margins are either computed or are inferred from supplemental direct drive testing. The Fault Insertion Method (FIM) offers an inexpensive way to directly demonstrate margin during a system-level EMP test. Moreover, margins obtained using FIM are directly related to the design margins required to offset known degradations observed on operational systems.

The FIM concept is thoroughly examined. FIM hardware design issues are discussed. Laboratory and system-level test data acquired on the EMP Test-Bed Aircraft are used to demonstrate the controlled effect of adding calibrated faults to cable shields and apertures. In addition, correlation is demonstrated between localized cw measurements and system-level EMP test transfer functions obtained on FIM components. Recommendations are made for the proper role of FIM in EMP validation, assessment, and hardness maintenance programs.

THE EFFECTS OF SIMULATED ELECTROMAGNETIC PULSE ON COMMERCIAL AIRCRAFT

by:

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ABSTRACT

An item of recent major interest within the EMP community has been the environmental impact of EMP simulators. One of the environmental concerns is the effects of the simulated EMP (SEMP) on commercial aircraft. Of particular interest are the effects upon flight critical digital systems, such as a Full Authority Digital Engine Controller (FADEC), integrated display systems (IDS), and Digital Fly by Wire (DFBW) flight control systems. Flight essential navigation systems are also of interest, but are not addressed here.

The purpose of this paper is to evaluate the susceptibility of commercial aircraft to the SEMP hazard based upon the Army's AESOP simulator. The following issues are addressed:

1. The AESOP environment at altitude.
2. Coupling to cables within commercial aircraft.
3. Known transient safe levels for commercial aircraft.
4. Determination of threshold levels.
5. Conclusions.

It has been found that data from commercial aircraft indicate the civil aircraft critical systems should not be adversely affected by SEMP levels up to about 15 kV/m. This is based on a limited number of data points, however. There is a much larger military data base, and it is found from this that perhaps a factor of 2 margin should be considered to bring the threshold level down to about 8 kV/m.

HEMP COUPLING TO SUBSTATION RELAYS

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Calculations of CHAP-fit HEMP coupling to relay circuits have been made using models validated against switching transient measurements in electric power substations. Comparisons of HEMP with AIS and GIS switching transients show considerable overlap in terms of amplitudes and bandwidths. Measured data and predictions using traveling wave models for the substation, transmission lines connected to the substation, and relay control wiring describe the different coupling modes and assess the amount of interference at the relay inputs. Transfer functions for several coupling mechanisms are described. The effect of relay load impedance versus frequency on the resulting interference waveshapes and peak amplitudes has been calculated using measured relay impedances.

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HEMP work sponsored by Office of Energy Storage and Distribution, United States Department of Energy under Contract DE-AC05-84OR21400 with Martin Marietta Energy Systems as operator of Oak Ridge National Laboratory.

TRANSIENT RESPONSE OF A DISTRIBUTION CIRCUIT RECLOSER AND CONTROL UNIT TO A HIGH–ALTITUDE ELECTROMAGNETIC PULSE (HEMP) AND LIGHTNING

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ABSTRACT

This paper presents an analysis of the response of a power system distribution line ecloser unit to a high altitude electromagnetic pulse (HEMP) and a lightning irect–strike excitation. From details of the configuration of the system, physical and athematical models are developed, and a study of possible HEMP responses is onducted. Two voltage and two current responses at selected points within the system re studied for both the HEMP and lightning stresses. The possibility of simulating the IEMP responses is also discussed, with predicted and measured responses being provided r the Advanced Research EMP Simulator (ARES).

This work has been sponsored by the Office of Energy Storage and Distribution of he U.S. Department of Energy, through the Oak Ridge National Laboratory, under ontract DE–AC05–84R–21400.

Title: A Method for Determining the Effects of Simulated Electromagnetic Pulse (SEMP) on Cardiac Pacemakers

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Adelphi, MD. 20783

A method was developed which employs both empirical and analytical techniques in determining the effects of simulated EMP (SEMP) on cardiac pacemakers (CPM's). This effort was initiated as one element of the re-evaluation of the Woodbridge Research Facility's (WRF's), environmental documentation for the operation of EMP simulators. Although specific to SEMP and WRF in application, this method may be used to determine the effects of any electromagnetic source on CPMs.

The system functions of pacemakers, in typical configurations, were determined experimentally via frequency domain measurements of coupled pacemaker lead currents. To facilitate the measurements, a radiating CW source was used to excite pacemakers embedded in an electromagnetic "phantom" (a test fixture constructed to represent a human body in both physical characteristics and electrical parameters). Computer-generated EMP waveforms were then convolved with the CPM system functions, and the results transformed to the time domain to produce the induced pacemaker lead currents. Numerous permutations of pacemaker, phantom, and field orientations were analyzed to develop the theoretical worst-case pacemaker response to the WRF EMP simulators. These worst-case currents were then used as the "model" for the output parameters of a current injector. While being monitored continuously, each pacemaker test sample was injected with a range of currents proportional to the predicted worst-case current to facilitate the determination of damage and/or upset thresholds, relative to the CPM's proximity to an EMP simulator.

Two independent analytical studies were performed in parallel with the experimental study to validate the experimental results. The first method utilized a buried transmission line model to predict the implanted CPM terminal currents. The second method involved incorporating a pacemaker into a 3-D computer code model of the human body to develop the frequency domain transfer function of an implanted pacemaker. The pacemaker lead currents were then determined through convolution with SEMP field predictions and transformations to the time domain.

Recommendations are submitted for further efforts in developing a more accurate simulation of human tissue (phantom) and evaluating a larger sample base of CPMs.

SOME SHARP BOUNDS ON WAVEFORM NORMS

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Attempts to standardize hardness verification and acceptance testing for electronic equipment have included characterizing simulated threat waveforms on cables using various norms. Norms used have included the peak value of the waveform, the maximum derivative of the waveform, the total energy in the waveform, and others. The result presented here shows that under modest assumptions, waveforms which represent the maximum attainable values of these norms can be identified. With the advent of waveform synthesizers which generate arbitrary waveform shapes, these waveforms may be useful test waveforms in the hardness acceptance testing of products.

Sharp bounds on the peak, peak derivative, and finite duration impulse norms are obtainable by restricting attention to strictly bandlimited, finite energy waveforms. These restrictions are reasonable in most contexts and introduce no real restrictions on plausible stress waveforms. A strictly bandlimited function h(t) may be represented as an infinite sum of sin(x)/x functions:

$$h(t) = \sum_{n=-\infty}^{\infty} h(n/(2B))\sin(2\pi B(t - n/(2B)))/[2\pi B(t - n/(2B))]$$

where H(f), the Fourier transform of h(t), is zero for $|f| > B$.

When, in addition, attention is restricted to finite energy functions, one may identify the coefficient sequences {h(n/2B) ;n = ..., -2, -1, 0, 1, 2, ...} with the Hilbert Space, ℓ_2. Waveforms which maximize or minimize a variety of norms may be determined (sometimes uniquely, up to a time shift) by applying the norm to the infinite series representation of the function. This frequently corresponds to a term-by-term application of the norm to the shifted sin(x)/x terms in the above series. Selecting the sample values h(n/(2B)) to maximize the sum subject to a requirement for finite energy then provides the waveform required. In the case of the rectified impulse over an infinite time interval, the maximizing function does not exist. In this case, the norm as formulated does not reflect a quantity which is useful in assessing the stressfulness of waveforms.

NORMS OF VECTORS OF TIME-DOMAIN SIGNALS PASSING THROUGH FILTERS AND NORM LIMITERS AT SUBSHIELDS

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This paper extends the use of filters and norm limiters from single time-domain signals to vectors of such signals penetrating subshields. This gives a general format for specifying the performance of protection of electronic systems in the presence of various electromagnetic environments.

ABSTRACT

THE EFFECT OF WAVEFORM PARAMETERS ON ELECTROMAGNETIC COUPLING

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This paper presents the results of investigations into the dependence of the degree of electromagnetic coupling to selected canonical geometries on the incident waveform parameters. Waveform parameters such as risetime, peak value, duration, carrier frequency are evaluated for their contribution to the total coupling to the canonical geometries. Simple geometries such as thin slots, apertures, conducting lines, dipole antennas, and cavities are addressed. A short discussion will be included regarding the relevance of the now popular waveform norms with regard to the effect of the coupled waveform characteristics on component response. The norms which are addressed include:

- Peak Value
- Rate of Rise
- Impulse
- Rectified Impulse
- Root Action Integral

Waveform characteristics which may tend to optimize the coupled response norms are also discussed.

FREE FIELD AND DIRECT DRIVE CABLE/WIRE RESPONSES

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Direct drive of electronic subsystems has been used extensively to evaluate subsystem hardness in the laboratory and to supplement Electromagnetic Pulse (EMP) free field simulator deficiencies to meet threat conditions. The direct drive techniques most often used consist of inductively driving the input cables of a subsystem with a series of independent damped sine waveforms. When this approach is used in conjunction with the hardness verification of a weapon system, the subsystems are normally driven insitu with power on. The results of the direct drive responses are normally compared with EMP free field cable response measurements extrapolated to threat conditions. The free field and direct drive measurements and comparisons are normally limited to bulk and not individual wire responses due to the large number of cables and wires involved. Comparison of a series of direct drive responses with a free field response presents the analyst with a "apples" and "oranges" problem.

The B-1B test approach used scaler norms for comparing the direct drive and extrapolated free field responses at the electronic subsystem or Line Replaceable Unit (LRU) cable connector. Other programs have used peak responses only, energy within frequency bands, etc. to make pass-fail safety margin comparisons.

A series of tests were conducted on the Electromagnetic Pulse Test Aircraft (EMPTAC) in the Weapons Laboratory's TRESTLE and HPD free field simulators as well as using the Mobile Universal Direct Drive (MUDD) van. Various cable current measurements consisting of over the shield bulk, under the shield bulk core, and wire responses for each individual wire within the cable bundles were made. Comparisions of these responses were made using the B-1B Norms, frequency domain overlays, and other techniques to determine the adequacy of damped sine direct drive techniques. Also evaluated were the bulk to wire ratios for the cables tested.

MEANINGFUL SPECIFICATIONS
FOR
INDUCTIVE CURRENT DRIVERS

By

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and

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The inductive driver is a very versatile tool in direct-drive testing applications. It provides a convenient means of directly injecting test currents into specific conductors without the need to break the conductors under test. One critical parameter in both the design and use of an inductive driver is the magnitude of the current that a specific driver is capable of delivering to the test conductor. Unfortunately, this parameter is often difficult, if not impossible, to determine from the manufacturer's specifications. The maximum current that a driver is capable of delivering is usually specified as an [Ixt] product in terms of the delivered output current. However this specification is valid only for single specific load impedances, which may or may not be close to the values encountered in testing.

Driver specifications in terms of a specific source impedance and a specific load impedance can be used to eliminate some of the ambiguity in driver specification. The behavior of the driver with other values of source and load impedances, particularly if these are complex (reactive) parameters, will then be significantly different than specified. This paper derives the theoretical performance of the inductive current driver in terms of the source and load characteristics, as well as those of the driver. The [Ixt] product is then redefined so as to incorporate complex load impedances, a few examples of which are presented.

This work was sponsored by EG&G for clarification of specifications of existing commercial products.

DIRECT-DRIVE WAVEFORM CONSIDERATIONS

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It is a common practice to supplement a simulator test program with direct-drive testing. Generally, the direct-drive levels are based on either common mode currents that were measured in the simulation or on data that were obtained from similar test program, e.g. the approach of MIL-STD-461/2. The transient waveforms generally used are damped sinusoids with Q factors near 20 where the frequencies are varied to cover the EMP spectral bandwidth. These waveforms represent the open circuit voltages that are induced in the cables through inductive or capacitive coupling. Drive levels are set by a calibration procedure that uses a configuration such as a shorted loop or a loop with a 100 Ohm load.

The argument that is used to support direct-drive testing is that the expected response from EMP illumination is a linear combination of damped sinusoids. Also it is argued that any responses would be bandwidth limited to a narrow frequency band so that a sequential coverage of the EMP spectral bandwidth would be adequate. This assumes that the spacing between the frequencies selected for the damped sinusoid testing does not leave gaps in the coverage. An algorithm is presented from choosing the direct-drive frequencies to ensure adequate spectral coverage occurs.

Another issue of considerable importance is the frequency dependence of the currents that are induced by the direct-drive technique. Since the impedance seen by the direct-drive coupler may differ considerably from the calibration configuration, the induced current waveform may differ considerably from the damped sinusoid. Data that have been obtained by direct-drive testing are used to examine this effect. Both damped sinusoid and square pulse waveforms are considered. Time domain and frequency domain data comparisons are also made for simulator and direct-drive measurements.

R^2SPG--A NEW TECHNIQUE FOR MEASURING UPSET SUSCEPTIBILITY THRESHOLDS OF LARGE SYSTEMS

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Upset testing, the determination of the susceptibility of a system to mission degrading non-permanent changes induced electrical transients , has been difficult to perform because existing simulators often cannot produce high enough fields so that the system can be stressed to the threat plus the desired hardness margins (6 to 26 dB). In addition, these simulators cannot produce use enough pulses during a test so that a reasonable proportion of the possible states of a digitally controlled system can be tested. Electromagnetically hardened systems must also be tested periodically in order to ensure that adequate margins to upset are being maintained. This is particularly true of environments such as lightning and the Nuclear Electromagnetic Pulse, which occur infrequently. While laboratory measurements are useful, a system level test of the complete system installed and operating in the vehicle or facility is most desirable since the response of the system is to a large extent determined by the interconnecting wiring. The waveform used to test the system should have an amplitude and rise/fall times that are recognized to be worst case for the system under consideration. The amplitude should be controllable so that damage can be minimized if some of the hardening elements have been degraded. For digital systems with many possible states, large numbers of pulses must be used to ensure that the susceptibility of all the states is tested.

A simple technique has been developed to meet the goals outlined in the preceding paragraph. It is called the Random Repetitive Square Wave Pulse Generator (R^2SPG) technique and uses of a charge line pulser, with a risetime of a few ns and durations in the range of 10 to 100 ns, inductively coupled to the cable system to stimulate the system. Since the cabling of most aircraft systems is compact and the various parts are closely coupled to each other, the current propagates throughout the system. The drive is increased until the current coupled to the system cables reaches the desired value. The amplitude of the output is easily controllable, as different from the chattering relay, by varying the voltage on the charge line. Peak cable currents up to 16 A are easily obtained. The resulting cable current is approximated by a damped square wave. Thus both polarities are obtained in one pulse. The ringing frequency of the transient is related to the resonant frequency of the cable system. Thus the pulser excites the cable system similar to the way that the cable is excited by the EMP. The pulser produces transients randomly at the average rate of 30 Hz, consequently, many thousands of events can be simulated and the probability of testing each state of the system approaches unity.

Upset tests, using the R^2SPG technique, of a personal computer and a large digitally controlled communication system showed that upsets occurred when the cable currents were in the range of several Amperes. In some cases, the upset occurred near the end of a 4 minute run, suggesting that the system was only susceptible to upset in a very small portion of the possible states.

The controllable output, the waveform, and the ability to produce cable currents up to 16 A with portable equipment make this pulser an ideal device for assessing upset hardness margins and for periodic hardness surveillance measurements.

COMPARISON OF R²SPG WAVEFORMS WITH SIMULATED EMP

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The Random Repetitive Square Wave Pulse Generator (R^2SPG) was developed for "In-Situ" upset testing of cable connected equipment. This pulser uses a charge line and and vacuum switch to produce a broadband transient that approximates a damped square wave with a rise time of the order of a few nanoseconds and a ringing frequency in the range of tens of MHz. A random repetition interval insured that the technique tested vulnerable states that only occurred repetitively and could be missed if a constant repetition rate was used. An average repetition rate of 30 Hz allowed thousands of pulses to be induced onto the system in a few minutes, thus insuring that almost all of the possible states of a digitally controlled system would be tested. The maximum output of this pulser was of the order of 16 to 20 A and was controllable. The R^2SPG is battery operated, self-contained , weighs 6.9 kg and is about 19 x 16.5 x 29 cm.

Conceptually, the R^2SPG is an "electronic hammer" that stimulates the system under test using a broadband waveform that is worst case in both amplitude and risetime. Since the waveform is a damped squarewave, it has many harmonics at the higher frequencies whose amplitude falls off as $1/f$ rather than $1/f^2$ as is the case for a damped sine wave. Since it produces a broadband transient, the cable under test should be excited at its resonant frequencies. Since currents 10 or 20 times those expected from a HEMP can easily be coupled to the cable system, hardness margins can be quantitatively determined.

A question that is frequently asked is "How does the R^2SPG waveform compare to the transients induced by EMP simulators?" In order to answer this question, measurements were made on three cables in the EMP Testbed Aircraft (EMPTAC) using the Horizontally Polarized Dipole (HPD) and Trestle EMP simulators as well as the R^2SPG and a damped sine wave produced by the MUDD van pulser. The currents were analyzed in both the time and frequency domains. The R^2SPG produced a greater induced current, by a factor of 4 to 60, than either of the EMP simulators. The pulse widths and the frequency content were similar for all of the test points obtained with the R^2SPG and EMP simulators and by careful selection of the charge and feed cables, could be made essentially identical. This confirms the assumption that the R^2SPG excited the cable system at its resonant frequency. The amplitudes of the R^2SPG and the damped sine wave from the MUDD van were closer to each other in both the time and frequency domains. The MUDD van was able to couple more energy to the cable when the lowest carrier frequencies (0.1 and 1 MHz) were used .

EFFECT OF CHARGE, FEED AND TEST CABLE LENGTHS ON R^2SPG WAVEFORMS

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The Random Repetitive Square Wave Pulse Generator (R^2SPG) was developed for "In-Situ" upset testing of cable connected equipment. This pulser uses a charge line and a vacuum switch to produce a broadband transient that approximates a damped square wave with a rise time of the order of a few nanoseconds, determined by the impedance discontinuities of the switch, and a ringing frequency that is related to the electrical length of the charge and feed lines.. Since the waveform is a damped squarewave, it has many harmonics at the higher frequencies whose amplitude falls off as $1/f$ rather than $1/f^2$ as is the case for a damped sine wave. Since it produces a broadband transient, the cable under test should be excited at its resonant frequencies.

In order to better understand the relationships between the lengths of the charge, feed and test cables, a controlled experiment was performed that varied each of these independently. Test configurations included external charge lines 0 and 7 m long, feed or delivery lines 2 and 3.65 m long and test cables 1.5, 3, 6, and 12 m long. The test cable was installed above a conductive ground plane to which the ends were electrically connected. The current waveforms were recorded and analyzed with a digital data acquisition system.

The currents induced on the test cable were consistent with a simple transmission line model. The ringing frequency of the pulser, determined by the electrical length of the charge and feed lines, was generally discernable as was the resonant frequency of the test cable. When these two frequencies were approximately equal, the induced current was a maximum. The peak amplitude of the transient and the decay rate of the pulse spectrum were unaffected by changes in the charge and feed lines. The amplitude of the spectrum at the ringing frequency decreases slightly with increasing charge line length.

These measurements confirmed that the R^2SPG excites the test cable at its resonant frequencies. This excitation is very similar to external field excitation, such as an EMP. In addition, these measurements showed that the R^2SPG waveform could be tailored to a specific test need.

PAWS 4000
A 320-kW POWER ARBITRARY WAVEFORM INJECTION AND ILLUMINATION SYSTEM

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PAWS 4000 FOR INJECTION TESTS

Standards, such as MIL-STD-461 C, recommend injection tests using dampered sinus waves for a given number of frequencies.

However, experience has shown that testing with discrete frequencies does not always allow testing the system under worst case conditions (resonnance frequency).

In addition, the current value given by these standards, are often inadequate for certain types of systems.

The proposed system not only allows reaching high level of power (320 kW), il also enables control of the signal waveform via digital synthesis.

The system is based on a pulse, distributed amplification which provides high power levels from a compact design.

The system consists of a high speed (800 M samples/s) signal synthesizer that allows generation of signals up to 100 MHz, a pulsed distributed pre-amplifier, a pulsed distributed amplifier, an injection clamp and a current sensor connected to a digital measurement chain for signal control.

The system can operate either in open or closed loop (with 2 or 3 firings in order to obtain the closest approximation to the desired signal (figure 1).

PAWS 4000 FOR MEDIUM LEVEL ILLUMINATION

Tests run in illumination mode use a standard EMP wave (double exponential). This waveform is that of the indicent wave.

The interaction between the incident wave and the object under test produces a field of a significantly different shape.

The electronic equipment placed in the object under test or in shielding is therefore submitted to fields whose shapes are different from that of the incident field and often at a level of 20 dB or more below that of the incident field.

Equipment can be tested either by illuminating the object with the incident wave (which provokes a specific field at the level of the equipment) or, for the first time, by use of a 320-kW generator to generate the desired field directly in a small-size simulator (figure 2).

A 2 x 1 m Crawford cell or 1-m stripe-line yields fields of 4 kV/m with a given waveform thus providing a compact and economic means of testing.

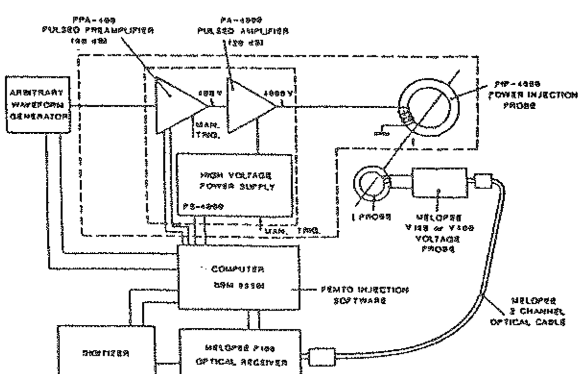

FIGURE 1

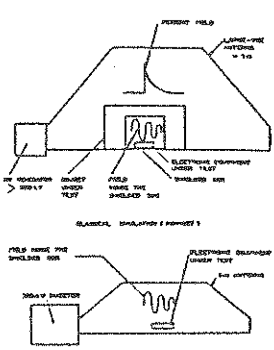

FIGURE 2

CAPABILITIES OF THE NAVAL AIR TEST CENTER'S CURRENT INJECTION DIRECT DRIVE SYSTEM (CIDDS)

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ABSTRACT

The EMP Section of the NAVAL AIR TEST CENTER is upgrading its Direct Drive System's capabilities. The new system (CIDDS) will have higher power and greater bandwidth than the old system (TADDS). CIDDS will also be fully automated as well as being mobile. This is in keeping with the NAVAIRTESTCEN's RDT&E philosophy of utilizing proven technologies to perform T&E on DoD systems. CIDDS is expected to meet almost all power output levels required to satisfy safety margin testing of defense systems.

This paper presents a detailed description of CIDDS and its performance characteristics. The CIDDS characteristics will also be compared to the TADDS characteristics to illustrate improvement.

Tools for cost effective simulation of transient electromagnetic disturbances

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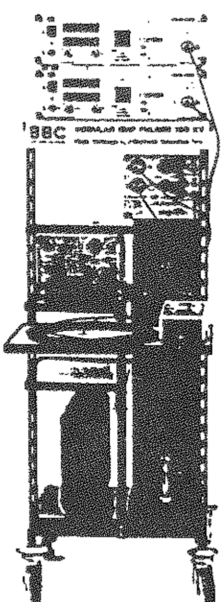
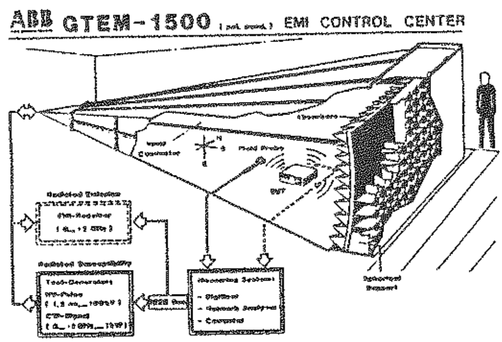
In electromagnetic effect engineering, after proper system analysis it is required to inject currents into systems and illuminate subsystems with electromagnetic fields. For EMP testing of trains, two facilities were developed:

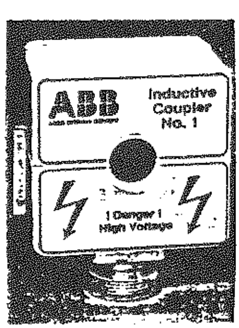
1. A previously described set of current injection generators (1 A to 80 kA, up to 100 kV, and frequencies acc.to Mil Standard 461C) has been augmented by the addition of a newly developed set of inductive couplers (short circuit peak current 16 kA / 120 kHz and 1 kA / 6.25 MHz) for cable testing.

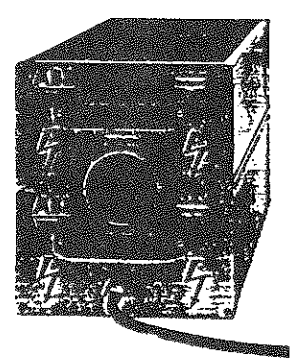
2. The GTEM-cell has been expanded in frequency range up to 18 GHz; preliminary pulse field data (52 ps rise time) will be shown. This facility can be used to generate precise TEM-fields including high voltage conditions.

Theoretical calculations and experimental results will be presented.









REVIEW OF UNCLASSIFIED HEMP CALCULATIONS AND ANALYTIC WAVEFORMS

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During the 1980's several open publications and conference papers have been published which include early-time ($t < 1$ μs) HEMP calculations produced with unclassified weapon parameters. These studies have included source parameters modeled by delta functions, decaying exponentials and triangular pulses. These calculations clearly show that HEMP waveform peak values are limited by a saturation effect, and that EMP waveform shapes vary with angle of incidence from the burst along with other factors. This paper will review this previous work in a coherent fashion.

A second aspect of recent HEMP work is the publication of several unclassified analytic waveforms to be used principally for coupling analyses. Several of these waveforms will be reviewed and discussed, especially in the context of the recent unclassified HEMP calculations.

Aircraft EMP Standards

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In 1982, under the direction of the Assistant to the Secretary of Defense for Atomic Energy, the Air Force was given the job of developing EMP standards for airborne systems for all of the services. The primary responsibility for these standards was assigned to Aeronautical Systems Division (ASD), and the Weapons Laboratory was directed to provide technical support.

Thus far in the Air Force Specifications and Standards Program, three documents have emerged. One is AFR-80-38 which defines the program requirements for the acquisition and deployment of EMP-hardened aircraft. The other two are the MIL-STD-461C Notice 2 and MIL-STD-462 Notice 6 which standardize the procurement requirements and tests for electronic equipment.

At the present time, the Air Force is completing a Military Standard which defines the system-level requirements for aircraft. This standard, which is being drafted by ASD and the WL, will be a replacement document for MIL-E-6051D. It is an overall electromagnetic protection requirements document for use in aircraft procurements, and it contains requirements for EMP along with EMI, EMC, Lightning, RF Hazards and other EM phenomena. To accompany this requirements document, the WL is also preparing a series of Military Handbooks. The first will be a Design Guideline for EMP hardening of aircraft. The second will contain instructions on verification, qualification tests and hardness surveillance methods for aircraft as well as guidance on the preparation of EMP hardening specifications.

Role of Standards and Specifications in EMP Hardness Verification and Surveillance

W. S. Kehrer and W. D. Prather

The DoD is actively developing HEMP standards and specifications. Some specifications such as the HEMP environment requirements have existed for some time. However these specifications require the system designer to make many assumptions in order to generate engineering design specifications for system hardening. The Weapons Laboratory is developing a number of system and subsystem level test techniques which enable hardening performance to be described in terms of measurable engineering quantities. This paper describes several of these test methods and illustrates their application to HEMP hardness verification and surveillance.

A REVIEW OF METHODS FOR ACCEPTANCE TESTING OF ELECTROMAGNETIC SHIELDING ENCLOSURES

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Recent improvements in hardware, operational procedures and an improved understanding of governing electromagnetic processes used for evaluation of the integrity of shielded enclosures have provided a need for review of current acceptance standards and the identification of possible additions or improvements that should be made in order for all such enclosures to be accepted using the same procedures. Examples of standards that present a significant contrast in scope and currency, come to mind immediately, the Mil-Std-285 (Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method Of), and the new Mil-Std-188-125 (HEMP Protection for Ground Based C^4I Facilities Performing Critical Time Urgent Missions). These standards could perhaps be combined if the proper thread of commonality was emphasized. The purpose of this paper is to review methods and techniques set forth in these standards and pose additional considerations that could improve the general use of standardized acceptance methods, and perhaps bring the standard acceptance procedures for mobile command posts, buried command posts, and surface and flying systems, with electromagnetic shielding requirements, closer to a common acceptance standard.

Another Look at the Beginnings of High-Altitude EMP

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For presentation at the 1990 NEM EMP Meeting
University of New Mexico
21-25 May, 1990

We review folklore associated with high-altitude EMP. Standard references give the basic history.[1-4] These reviews lead to much balanced, valid information. Highlights include Enrico Fermi's 1945 prediction of electrical signals from the Trinity burst, Richard Garvin's 1954 use of EMP for diagnostic information, Bethe's 1957 predictions for high-altitude EMP, Wesley's 1958 predictions for high-altitude EMP, and the climax realized with the Karzas and Latter and the Longmire works in 1964.

One neglected highlight is proposed: credit to C. H. Papas for his 1951 suggestion that the Compton effect provided the basic driver for EMP production. Support will be furnished for this credit.

Closer examination of the folklore leads to data that have been shadowed, neglected, and even exaggerated. Shadowed data include those taken by experimentalists in August 1958 showing the large signals and the east-west asymmetry in the EMP generated by the Teak and Orange high-altitude bursts. These data remained in the shadows until after the 1962 test series, where they could have been useful. New illumination of neglected Hawaiian streetlight data allowed those data to be understood.[5] Some exaggeration is both needed and justified, such as that necessary to generalize a worst-case threat, but other exaggeration is neither needed nor accurate. For example, the TV film, "The Day After" exaggerated the EMP effects, where not one automobile or truck would operate and no electrical power or telephone system survived. Rather than a concerted effort to substitute reason for the distortions generated by exaggeration, some attention ought to be directed toward shedding light on shadowed and neglected features of past problems. Several possibilities will be noted.

[1]K. S. H. Lee, Editor, EMP Interaction: Principles, Techniques, and Reference Data, Hemisphere Publishing Corporation, New York, 1986.
[2]C. L. Longmire, On the Electromagnetic Pulse Produced by Nuclear Explosions, IEEE Trans on Antennas and Propagation, AP-26, No.1, January, 1978, p3.
[3]C. L. Longmire, Early Time EMP from High-Altitude Nuclear Explosions, Mission Research Corporation Report DNA-TR-84-175, 1 December, 1983.
[4]W. A. Radasky, W. J. Karzas, C. W. Jones, and G. K. Schlegel, High-Altitude Electromagnetic Pulse - Theory and Calculations, DNA-TR-88-123, October 1988.
[5]C. N. Vittitoe, Did High-Altitude EMP Cause the Hawaiian Streetlight Incident?, SAND88-3341, April 1989.

SAND89-2311A

DEVELOPMENT OF MIL-STD-188-125

MILITARY STANDARD

HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) PROTECTION FOR GROUND-BASED C3I FACILITIES PERFORMING CRITICAL TIME-URGENT MISSIONS

Presented by Hugh H. Pohle,
Weapons Laboratory/NTCAC (Air Force Systems Command)
for the MIL-STD-188-125 working group

The Assistant Secretary of Defense for Atomic Energy directed that standards be developed for EMP environments and for the hardening of systems. The first result of this program was MIL-STD-2169, which specifies the HEMP environment. MIL-STD-188-125, which is now in the formal coordination cycle, will be the next to appear.

MIL-STD-188-125 sets fourth the minimum requirements for "low risk" protection of ground based C3I facilities*, from the MIL-STD-2169 environment. The requirements are stringent in order to avoid both damage and upsets. The standard's use is mandatory only for a select set of C3I facilities that perform time-critical missions. The basic requirements are:

1. Enclose all possible mission essential equipment within a high quality EM shield (nominal 100dB).
2. Minimize the number of penetrations, fiber optics required.
3. Protect all remaining penetrations.
4. Electrical penetration protection devices outputs must be below specified limits when driven by specified current waveforms. Limits are stated in terms of four norm parameters.
5. Additional measures specified for special cases.

The standard also addresses testing. An acceptance test of the shiel and all penetrations, upon completion of facility construction, is required. A second "verification" test of the shield and all penetra tions is required after the facility becomes operational. During thi test all electrical penetrations must be driven while in operation, t determine if the system suffers damage or upset. MIL-STD-188-125 includes three appendices that detail HEMP unique test procedures. Appendix A describes a shielding effectiveness test after MIL-STD-285 Appendix B describes the pulsed current injection test. Appendix C describes a shielding effectiveness test using the continuous wave immersion technique. It is intended that these proce dures will ultimately be put fourth as separate standards.

* The standard thus far covers only fixed facilities. Work on a second volume, covering transportable systems, is just beginning. In addition MIL-HB-423, to assist users in the implementation of MIL-STD-188-125, is currently in preparation.

EMP ACTIVITIES IN FRANCE : AN OVERVIEW

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Ministry of Defense

This presentation will be an instant photography of the EMP activities in France from a technical standpoint ; the discussion will be limited to the unclassified area.

In the recent years, a full set of numerical computation techniques has been developped to analyse and to quantify the effects of an EMP on the systems of interest ; few of them will be presented together with some examples of calculation. An important effort has been achieved in the simulation sector to develop the ability to analyse the coupling and validate the hardening techniques. The panoply of the most important simulators will be shown and their performances evaluated (HPD, SSR, SIEM, ...).

ELECTROMAGNETIC PULSES AND HUMAN HEALTH

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An analysis based on distributed body impedance measurements and the Lawrence Livermore National Laboratory (LLNL) NEC method of moments indicate that the maximum induced current in humans exposed to a typical 10 nanosecond rise time Electromagnetic Pulse (EMP) is approximately 5 amperes per 1 kilovolt per meter electric field strength.

New results and measurements indicate dependence on the size of the body exposed to EMP. One cannot form a one to one comparison between currents induced in, i.e., rats, and humans.

RADAR TARGET DISCRIMINATION USING TRANSIENT EM PULSES

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Interaction of a transient EM wave with a conducting object has been studied by many researchers for some time. The Singularity Expansion Method (SEM) [1] has provided a theoretical tool for these studies. One motivation for these studies is the utilization of transient EM waves for the purpose of discriminating and identifying radar targets.

A new radar target discrimination scheme based on the natural resonant frequencies of the target has been developed recently. This scheme consists of synthesizing aspect-independent discriminant signals, called E-pulses, S-pulses and K-pulses etc., for the target [2]. These pulses are used to annihilate or extract natural resonant modes from the late-time transient response of the target. When the discriminant signals of a target are convolved numerically with the late-time pulse response of the target, the convolved outputs will be zero or a single-mode waveform. If the discriminant signals for an expected target are convolved with the pulse response from a different target, the convolved outputs will be significantly different from the expected zero or single-mode waveform. Thus, the differing targets can be discriminated.

A sound theoretical understanding of the E/S-pulse [3] or K-pulse schemes [4] has been achieved. The scheme has also been tested in time-domain scattering ranges using scale models of various aircraft [2,3]. The experiments have verified the aspect-independence as well as the noise-insensitivity of the scheme.

Future needs for this research program include (1) a source for generating high power EM pulses of about 100 ns duration, and (2) a directive antenna system for radiating and receiving short EM pulses. For the latter need, an antenna array of impedance loaded dipoles or an EM missile launcher will be investigated.

[1] C. E. Baum, Transient EM Fields, L. B. Felson, Ed., Springer-Verlag, 1976.
[2] K. M. Chen, et al., IEEE Trans. APS, July, 1986.
[3] E. J. Rothwell, et al., IEEE Trans. APS, April, 1987.
[4] M. A. Morgan, Journal of EM Waves and Appl., 1988.

Pulsed Sources of High Power Microwaves:
The State of the Art

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The application of modern developments in pulsed power technology to the generation of microwaves has had a revolutionary impact on output power capabilities. A world record level of 15 GW at 9.4 GHz has been established, and gigawatt power levels have been recorded for frequencies ranging from below 1 GHz to 50 GHz. In these intense pulses, energies of 500 J have been produced in a single pulse.

The first part of the talk will be devoted to an overview of the variety of sources that have been used in the pulsed generation of high power microwaves. These include relativistic-beam versions of well-known sources such as the magnetron, klystron, and backward-wave oscillator/traveling wave tube, plus more recent entrants to the field like the gyrotron, virtual cathode oscillator, and free electron laser. Some of the outstanding achievments in peak power and energy production will be reviewed, and the most likely frequency ranges of application for the various devices will be discussed. Particular attention will be devoted to the Soviet multiwave devices that have produced gigawatt power levels over a wide range of frequencies. Developments in the research areas of pulse-lengthening at high power levels, repetitive operation, and mutually coherent generation in multiple sources will be reviewed. Finally, some opinions on the future directions in the field will be offered.

CW Test Technique — a Preferable Method for Assessing the Electromagnetic Vulnerability in Large Telecommunication Facilities.

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Abstract.

Testing and hardening verification is an important phase in the procedure of protecting electronic systems against electromagnetic interference. In many cases the electromagnetic threat is considered to be of transient character like EMP and sabotage pulses as well as lightning currents, switching overvoltages and electrostatic discharges, which naturally leads to the use of pulse testing. The CW testing technique constitutes an alternative method which in certain cases provides some incontrovertible advantages in the possibility of carrying out tests under normal system operation as well as a simpler antenna construction and no need for expensive pulse generators.

In the initial phase of an extensive Swedish Telecom EMP susceptibility test program a number of large fixed installations have been tested by means of CW test techniques. The used technique implies both amplitude and phase measurements and the acquired data have been possible to extrapolate to the time domain with an arbitrary threat.

The measurement program includes both field illumination and current injection. The CW technique which does not interfere with systems in operation has proven to be very effective for determination of EMP interaction in telecommunication facilities.

A number of illumination antennas have been developed for the test series. For antenna evaluation extrapolated CW data have been compared to transient EMP simulator response. The comparisons demonstrated a very good agreement between CW and pulse tests.

This paper describes the ideas of the test program as well as the advantages and disadvantages of the CW test technique as opposed to traditional pulse testing. Furthermore, it will be presented the experience gained from CW tests carried out on a telephone exchange station, a radio/TV broadcasting station and a computer centre.

USING DOCKSIDE CW TESTING FOR SHIP EMP HARDENING AND HARDNESS ASSESSMENT

By

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CW testing can be a valuable tool for ship hardening and hardness assessment. Inexpensive, portable CW measurement systems can be set up at dockside or aboard ship to provide ongoing hardness assessment and diagnostics during construction, modification and overhaul. Since CW testing is a low-level, non-hazardous technique, no special employee or ordnance precautions are required.

The Naval Surface Warfare Center has developed test techniques, antennas and measurement systems for doing such testing. The Defense Nuclear Agency is presently using similar techniques for EMP hardness assessment of ground-launched cruise missiles. An overview of the test techniques, antennas and measurement systems used by both these agencies will be presented, with emphasis on applicability to ship testing.

This work sponsored by Naval Sea Systems Command, Washington DC 20362

Onboard LLCW Illuminator for Naval Ships

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A single wire antenna has been designed and tested which will enable the use of LLCW techniques onboard Navy ships for EMP response prediction and an HM/HS program. The new antenna has been constructed and installed on the mast model at the NSWC EMPRESS site in Solomons, MD. The antenna response and a comparison to data taken during previous tests response and a comparison to data taken during previous tests of the mast will be presented. Methods for installation and use in overall assessments of large shielded structures will be discussed.

EXCITATION OF AIRCRAFT FOR HARDNESS SURVEILLANCE USING THE AIRCRAFT'S OWN HF ANTENNA

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Excitation of aircraft by driving the intersection of the fuselage and the wing at the aircraft's resonant frequency has been shown to be useful for hardness surveillance measurements. This technique for electromagnetically exciting aircraft produces surface magnetic and electric field distributions that are similar to those that result from exposure to plane waves. This excitation technique has been simplified by driving the aircraft's HF antenna. Surface magnetic fields in the range of 1 to 10 mA/m were easily produced. In addition to exiting the fundamental resonances, the response in the frequency range from 10 to 100 MHz was relatively uniform. This allowed some of the aperture hardening features to be evaluated at the apertures resonant frequency.

Apertures, such as window screens and gasketed doors were characterized by measuring the ratio of the magnetic field on the surface of the aircraft to the magnetic field a prescribed distance from the inside surface of the aperture using a multi-turn loop sensor and a battery operated field strength meter. These measurements were consistent with both theory.and other measurements of the same hardening elements.

This method offers convenience and flexibility. The necessary equipment is small, portable, and readily obtainable commercially. Thus, it is a meaningful hardness surveillance tool capable of quickly characterizing an aircraft's shielding elements to within a factor of two (6 dB), and determining where the most significant "hot spots" are.

EVALUATION OF FRENCH C.W TEST

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ABSTRACT

During the E-6A TACAMO Production Aceptance Test (PAT) No. 5 of aircraft TO258. A French C.W System test was conducted on 26 October 1989 . It utilized a measurement system designed as the HM/HS tester manufactured by Les Cables de Lyon, France.

The French C.W system measures aircraft shielding in two modes- global and local.

-In the global mode: the entire aircraft is illuminated externally by a transmitter and antenna radiating a single continuous frequency wave of approximately 80 MHz. The receiver, current probes and E-field antennas were used to measure the signal level at selected locations on the inside of aircraft. Field levels inside were approximately 60 dB below the reference value of the external field at the tip of the aircraft. When the forward lower lobe access door was opened, the cockpit field increased by 14 dB. 11 of 25 test points exhibted signal level 6 dB above reference.

-In the local mode: the extenal transmitter drives a skin current probe which is placed in close proximity to an aperture such as the personnel entry. During the test the transmitter drives skin current at 2 MHz onto the exterior of the aircraft in the vicinity of the lower lobe door. The leak age through the door is measured using the E-field probe. The attenuation measurements with door close averaged 25 dB. Introducing a deliberate degradation in the lower lobe door reduced the attenuation by 6 dB.

To incorporate the FRENCH C.W system into fleet Phase Maintenance Procedures it is necessary to eliminate the use of break-out boxes with their time consuming installation time. The C.W test would be then be conducted by measurering over the shields of the 25 selected cables. Also the amount of allowable degradation (dB) before maintenance action is preliminarily performed is not easily established , but it can be initially set at 20dB. Also, the receiver batterry has a short life, but AC or DC power of the aircraft can be used to supply receiver power.

The French CW system is a viable alternate to replace or supplement existing HM/HS techniques. The method is potentially cost and time effective option for an EMP test program.

ON AIRCRAFT EXTERNAL RESPONSES DRIVEN FROM AN ON-BOARD HF ANTENNA

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The first problem in the development of a program for monitoring the electromagnetic shielding of military systems is the selection of an appropriate test procedure. This diagnostic testing can be best accomplished by the global illumination of the shielded configuration. It has been proposed that for a hull-hardened aircraft the illumination can be developed by driving the HF antennas.

Typical locations for the HF probe antennas are the vertical stabilizer and the wing tips. The illumination of an aircraft from these antennas is examined theoretically by considering a Boeing 707 aircraft. The surface current and charge densities are obtained numerically from the body of revolution aircraft model. Shadowing effects are also considered.

The effectiveness of the HF antenna illumination is evaluated by comparing the SEM modal excitation as well as the resulting surface current and charge with that occurring under plane wave illumination. The radiated field from the HF probes is obtained by assuming a sinusoidal current on the probe with a unit current source.

It is shown that the HF antenna drive provides adequate illumination for the resonant frequency regime of the aircraft. Problems with using this approach to monitor the shield performance are identified.

Hardness Surveillance for Measuring System Hardening Degradations

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The use of surveillance testing in modern military weapons system is justified for many reasons. Although one common argument for using a surveillance testing program is to detect any changes in the "as delivered" or specified state of hardening of the system, many other surveillance testing objectives would exist in a comprehensive maintenance/surveillance program. Since most current military systems have regular upgrades for component sub systems, testing to insure proper installation of the new equipment so that hardening is not compromised would be one example. Another example would be to check the condition of hardening elements after a specific preventative maintenance action, i.e. the integrity of cable shields after interface cable replacements.

In order to use a surveillance testing method to detect actual hardening degradations on a system, it must be demonstrated that this test technique produces results which can be related to comparable measurements obtained in a threat level simulator. Without this correlation, it is difficult to justify that the change in measured test results signifies an important change in the hardening of a system. Free field CW techniques are currently being investigated for their applicability to this problem for measuring changes in stress reduction. Arbitrary waveform generators and square wave generators have been proposed as test equipment which would provide comparable measures characterizing changes in system strength. Regardless of the surveillance techniques adopted, an audit trail must be developed which establishes this link between the results of the threat level testing which established the initial hardness of the system and the results of the surveillance test.

Strategies for using FFCW techniques to detect important or significant hardening degradations will be discussed using EMPTAC data obtained both in high level pulse and the HSI free field simulators. Techniques using degraded and baseline data in both types of simulators will be presented to illustrate a candidate method for detecting significant hardening degradations. Simple bounding measures of frequency domain data will be used whenever possible to detect degradations, enforcing comparable bandwidth limitations on the pulse and CW data. The role of error quantification will be discussed in establishing the limits of acceptable deviation for surveillance testing results.

USING THE SINGLE POINT EXCITATION TECHNIQUE TO MEASURE APERTURE IMPEDANCE OVER A BROAD FREQUENCY RANGE

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Single Point Excitation for Hardness Surveillance (SPEHS) techniques have been used to produce surface fields over a broad frequency range (essentially 1 to 100 MHz). These fields were used to measure the aperture impedance of hardened and degraded windows and doors of the EMPTAC. Two kinds of aperture impedance can be defined. Analogous aperture impedance (sometimes called simply aperture impedance) is defined as the voltage across the aperture, in the direction of current flow, divided by the current intercepted by the aperture (surface magnetic field times aperture width). Specific aperture impedance is defined as the voltage across the aperture divided by the short circuit magnetic field on the surface of the aperture. Measurements were made using wing root (normal SPEHS) as well as antenna excitation. Values of aperture impedance were comparable to, but did not exactly match, those measured using the aperture tester technique. This technique has great potential because it could facilitate shielding and conductive penetration measurements when the aircraft is pressurized and/or in flight.

STRUCTURED PLANNING AND TESTING
AT
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EMP FACILITIES

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ABSTRACT

The DoD has required all military services through DoD Directive 4245.4 "Acquisition of Nuclear Survivable Systems" to address survivability to nuclear environments in development, ransition and maintenance of military systems. The Navy has adopted this directive and issued OPNAV Instruction 3401.3A "Nuclear Survivability of Navy and Marine Corps Systems" as the equirement for Navy systems.

This requirement directs program managers to develop requirements for new systems and lefine requirements for updates and changes to existing systems. Degrees of hardness for existing ystems which are critical DoD assess must also be defined. To support the program managers in heir Nuclear Electromagnetic Pulse (NEMP) hardening and survivability improvement programs, NAVAIRTESTCEN has developed a capability at the Naval Air Station (NAS) Patuxent River for esting Navy and other DoD systems.

This paper summarizes the capabilities at NAVAIRTESTCEN and the requirements for onducting testing at the facilities. Since the test philosophy at NAVAIRTESTCEN is "Test and Evaluation" a very structured test program can be conducted at relatively low costs. The paper resents the structured approach to be used as well as the flexibilities the user can call upon. The ser of the NAVAIRTESTCEN facilities can determine the approach for his program and NAVAIRTESTCEN can support him as required.

A TRANSPORTABLE, FOUR-CHANNEL EMP DATA ACQUISITION SYSTEM

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ABSTRACT

In Electromagnetic Pulse (EMP) testing, data acquisition systems tend to be very large and immobile. Although powerful in terms of data acquisition and processing flexibility, they often cannot be used effectively under conditions which require much mobility. They also are often difficult to use in situations where only a small amount of data is to be gathered, or where time is limited. It would be desirable to have available for such situations a small, transportable data acquisition system which would be simple to operate and move around. For a program to acquire high-altitude EMP data, BDM International developed a transportable four channel data acquisition system for use in a helicopter.

This paper provides a description of the system and its components, the software developed for the system, examples of EMP data acquired, and some of the other expected applications of such a system.

The overall system, including the field sensor package, had to be designed to meet the weight limitations imposed by the helicopter lift restrictions. The system consists of a pair of two-channel digitizing oscilloscopes, four remotely controlled fiber optic links, a PC-AT compatible laptop computer, a DC-to-AC inverter to supply power, and a rack to mount the equipment. The software was developed at BDM International on a desktop mockup of the system. The system was assembled and tested at an EMP facility at Kirtland AFB. Final changes were made to the system to make it more flexible and eliminate any bugs which remained, at BDM prior to the high-altitude field mapping effort. The system was then used to collect data in a helicopter at another EMP site.

RAPID SURVEY INSTRUMENT (RSI)
A Portable Data Acquisition System

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Historically, EMP testing activities have sought to characterize the hardness of a tactical system by acquisition and analysis of response waveform data. This was accomplished by repeated exposure to a simulated EMP environment while recording the waveform data for further analysis using complex data acquisition and processing systems. Both initial characterization and hardness maintenance are supported with this testing methodology. Access to peak response data at a test point reduces the cost of initial characterization by allowing planned measurements to be pre-screened. Hardness maintenance would be simplified by providing low cost empirical comparisons to previously made measurements without the use of a complex data acquisition and processing systems.

A Portable, battery powered, data acquisition instrument has been developed for rapidly conducting peak data surveys at specified test points on a test article. This Rapid Survey Instrument (RSI) has a dynamic range greater than 60 dB, a band-pass from 10 kHz to 160 MHz, and is approximately the size of a shoe box. The RSI is designed to record peak levels for up to 1000 measurements and display the data in the desired engineering units. An instrumentation and test point database resides in the RSI (non-volatile), allowing it to make the necessary conversions and support almost any external instrumentation configuration. The RSI contains an optical (serial) interface which can be used to communicate with a PC or hand-held terminal. A custom software program is available for an IBM compatible PC, providing remote control functions and a variety of data manipulation utilities. The source database can be created on the PC or downloaded from a separate test database and includes such information as test point identifiers, experiment numbers, instrument conversion factors, and peak data from previous measurements. Acquired peak data can be compared to previous measurements or specified thresholds in the RSI, in the PC, or uploaded back to the hose and merged into the original database.

The operational capabilities of the instrument will be described in detail. Results from laboratory measurements will be shown providing comparisons between waveforms acquired with high speed digitizers and data taken with the RSI. Discussions will be presented on the use of the RSI for prescreening test points and for the performance of hardness maintenance testing.

This work sponsored by Naval Sea Systems Command Washington, DC 20362.

EMPRESS II SOFTWARE UPGRADES

By

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EMPRESS II and the first EMPRESS II DAAPS was first employed as a system on the MOHAWK test in 1988. This test revealed a number of problems, some of which involved the DAAPS software. The concept of operations has evolved to require several changes as we learn how best to support EMP testing at sea. Many of the problems involved user training, and there were a few bugs which simply refused to present themselves until we reached the final acceptance test phase.

The upgrades include improvements in the user interface; tracking, reporting and diagnostics; increased functionality; added features to support emergent user needs; and those which generally supported reduced system loading and higher system performance.

Among the more significant topics to be discussed are: an improved user interface menu; a "quick-planning" mode for ad hoc measurements; a comprehensive diagnostics report; simplified instrumentation and measurement description; expanded data file headers and documentations; and added data analysis functions.

This work sponsored by Naval Sea Systems Command, Washington DC 20362.

EMPRESS II/DAAPS STATUS AND SHIP TEST LESSONS LEARNED

By

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The first ship test using the EMPRESS II EMP test facility was successfully completed in August, 1989. This test employed the EMPRESS II and the first (of three) Data Acquisition and Processing Systems (DAAPS) to accomplish pulser verification (including resolution of problems in achieving full rated output experienced in 1988 acceptance tests), DAAPS AT&E and evaluation of the hardening measures implemented on the USNS MOHAWK, T-ATF 170. The MOHAWK has been hardened to serve as the towing platform for EMPRESS II for ship tests beginning in 1990.

This paper will report accomplishments and "lessons learned" on the MOHAWK test, and will summarize changes made in response to our test experience and the current status of the DAAPS. By the time NEM is held, all DAAPS will have completed acceptance except for two days at sea on the USS DEYO, a SPRUANCE class destroyer, now scheduled for July.

This work sponsored by Naval Sea Systems Command, Washington, DC 20362

THE NAVAL AIR TEST CENTER EM INSTRUMENTATION SUITE

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ABSTRACT

The Naval Air Test Center (NAVAIRTESTCEN) has implemented significant upgrades to their EMP and Lightning testing facilities. The testing facilities at NAVAIRTESTCEN include the TACAMO Electromagnetic Pulse Simulator (TES), the Naval Aircraft Vertical Electromagnetic Pulse Simulator (NAVES), and a Lightning Simulator. The upgrades to these facilities include the addition of a state-of-the-art EM Instrumentation Suite that is capable of acquiring data in greater quantities and processing the results much faster than previously possible. The NAVAIRTESTCEN has also improved their direct-drive testing capabilities using state-of-the-art test equipment and techniques.

The two major EM Instrumentation Suite components are the TES Data Acquisition and Processing System (TES DAPS), and the Portable Data Acquisition System (PDAS). The TES DAPS is used for acquiring and processing time domain EMP responses of test objects that are tested in the TES DAPS and NAVES EMP simulators. The data is acquired using 18 channels of computer-controlled fiber-optic links and digitizers. The data is processed on a MicroVAX II based computer system. The TES DAPS uses a relational data base to set up and store relevant test object and instrumentation data for each test. This data base provides for standardized test planning and test reporting which enhances test efficiency. The PDAS is used for acquiring data from test objects in the Lightning simulator. This data is downloaded to the TES DAPS System for full data processing.

This presentation provides information about the NAVAIRTESTCEN's testing capabilities with focus on recent enhancements to these facilities. Insight into the EM Instrumentation Suite (TES DAPS, Lightning DAPS, and Direct-Drive) testing capabilities such as automated and standardized test planning features, test setup verification, near-real time data processing, automated test reporting, and test performance enhancements are addressed as well as highlights of their utilization.

ON-LINE QUICK-LOOK ANALYSIS CAPABILITIES AT THE NAVAIRTESTCEN

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ABSTRACT

A powerful tool for quick-look analysis of EMP stress response data exists on-line at the TACAMO EMP Simulator (TES) facility located at the Naval Air Test Center (NAVAIRTESTCEN) in Patuxent River, Maryland. Capabilities discussed in this paper are provided to TES facility users by the resident Data Acquisition and Processing System (DAPS).

This paper presents a summary of quick-look analysis capabilities provided to facility users by the DAPS. A brief overview of the DAPS, quick-look analysis capabilities, and examples of available automated reports are provided. Data presented in these reports were acquired in support of the Fleet Aircraft Assessment for Navy Testing and Analysis for EMP Limitations (FAANTAEL) A-6E Intruder EMP Evaluation effort, conducted at the TES facility from 19 June 1989 through 1 July 1989.

This work was sponsored by the Commander, Naval Air Test Center, Patuxent River, MD.

This work was sponsored by the Commander, Naval Air Test Center (NAVAIRTESTCEN), Patuxent River, MD. This presentation is unclassified.

TEST PLANNING METHODS FOR EFFECTIVE POST TEST ANALYSIS USING THE NAVAIRTESTCEN'S DATA ACQUISITION AND PROCESSING SYSTEM (DAPS)

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ABSTRACT

A dilemma exists between ("complete") testing requirements and available schedule and budgetary constraints for most EMP test programs. The emphasis as such should be on getting maximum return using available limited resources. A structured test planning approach, such as that used during the SH-60B test program, maximizes test program efficiency during the test conduct phase and more importantly during the post-test data analysis and reporting phase. This unique test approach provides in depth characterization of the weapon system's EMP response (both functional and transient responses), and produced results that provided insight down to the pin, LRU, major functional equipment category, and major compartment or EM zone. Using data base manipulations, a combination of sorts, searches, and graphical data presentations produced quick-look results, as well as an in-depth understanding of the weapon system responses.

This presentation addresses the highly successful SH-60B EMP test planning approach as it relates to future test planning efforts.

THE HDL FAST TRANSIENT MEASUREMENT SYSTEM (FTMS)

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ABSTRACT

The Harry Diamond Laboratories (HDL) Fast Transient Measure-
ient System (FTMS), located at the Woodbridge Research Facility
.n Woodbridge, VA, is a newly installed system that was developed
'or studying subnanosecond risetime EMP responses on mobile
round based command, control, communications, and intelligence
C^3I) systems. The FTMS consists of state-of-the-art gigahertz
andwidth fiber-optics and transient digitizing equipment, and
'C-based computer control equipment, necessary to support testing
o a recently established HEMP standard.

This paper describes the hardware, system specifications
bandwidth, signal to noise ratio, gain compression, etc.), and
omputer control software that comprise the FTMS. This paper
lso discusses lessons learned when integrating equipment in a
ystem such as the FTMS. This program was sponsored by HDL under
ontract DAAL02-86-D-0042.

EMP Simulator Test Results of a Composite Helicopter (SH-60B)

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ABSTRACT

The SH-60B SEAHAWK helicopter was tested at the TACAMO EMP Simulator (TES) and Naval Aircraft Vertical EMP Simulator (NAVES) at the Naval Air Test Center (NAVAIRTESTCEN) in Patuxent River, MD.

The SH-60B SEAHAWK is the Navy's version of the basic Sikorsky model S-70 helicopter. It is the airborne portion of the Navy's Light Airborne Multi-Purpose System (LAMPS Mk-3). The SEAHAWK's primary roles are antisubmarine warfare and anti-ship surveillance and targeting. Although the SH-60B has not been EMP hardened, it has been EMI hardened to operate in shipboard EM environments, and thus has several EMP protection features.

The SH-60B test conducted in the late winter 1988 involved the first usage of the Navy's new TES DAPS. The test implemented a structured automated test planning approach designed to maximize test outcome and simplify the post-test data reduction and analysis efforts while satisfying test objectives in a cost effective manner.

A total of seven experiments were performed on the SH-60B SEAHAWK helicopter as described below:

Experiments performed at the horizontally polarized TES facility:

- power-on safety demonstration
- power-on active systems operational evaluation
- power-off parallel (baseline) orientation
- power-off perpendicular orientation
- 28 meter off axis orientation
- power-off ground-alert parallel orientation

Experiments performed at the vertically polarized NAVES facility:

- power-off nose-on orientation at the NAVES facility.

An overview of measured EMP responses by equipment functional category, major equipment location, and unique measurement type categories are presented. Other significant aspects of the analysis effort such as direct drive recommendations, repeatability data, and experiment to experiment comparisons, will also be presented.

EMP Simulator Stress Results of the VH-60 Helicopter EMP Qualification Test

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ABSTRACT

The VH-60 Executive Transport Helicopter was tested at the Naval Air Test Center's (NAVAIRTESTCEN) TACAMO Electromagnetic Pulse Simulator (TES) and Naval Aircraft Vertical Electromagnetic Pulse Simulator (NAVES) facilities. The test was conducted as part of the VH-60 EMP Qualification Test program and utilized the test resources available at the NAVAIRTESTCEN including the Navy's new TES DAPS (TACAMO EMP Simulator Data Acquisition and Processing System).

The VH-60 airframe is constructed of conventional monoque light alloy construction. Fiberglass and Kevlar composite materials are used for cockpit doors, conopy, fairings, and parts of the cabin floor. The VH-60 has been hardened to EMP environments.

Six different experiments using four different helicopter orientations were performed on the VH-60 using the NAVAIRTESTCEN's two EMP facilities. Power-On Safety Demonstration, Power-Off Baseline, Fix Effectiveness, and 28m off-axis experiments were performed at the horizontally polarized TES facility. Nose-On and Broadside experiments were performed at the vertically polarized NAVES facility. The VH-60 test points were categorized into 13 location zones and 42 helicopter sub-systems. The majority of the measured responses were individual wire currents, core currents, and bulk cables currents. Measurements were not performed on cable shields.

This paper presents an overview of measured EMP responses by equipment functional category, major equipment location, and unique measurement type. Summaries of these results will be presented in histogram format. The direct drive recommendation methodology and results will also be presented, as well as other significant aspects of this analysis effort.

EMP STRESS RESULTS COMPARISON FOR SH-60B, VH-60 AND UH-60A HELICOPTERS

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ABSTRACT

Three H-60 aircraft (SH-60B, VH-60 and the UH-60A) were tested for susceptibility to the effects of electromagnetic pulse (EMP). The electromagnetic (EM) hardening for the three aircraft varied from no EM hardening (UH-60A) to hardening for a shipboard EM environment (SH-60B) to complete EM hardening (VH-60).

This paper presents a comparison of measured EMP responses (stress) for these H-60 aircraft. A brief overview of the weapon system EM topologies and test systems is presented first followed by a comparison of measured results by functional equipment categories, major compartments, and measurement types.

This work was sponsored by the Commander, Naval Air Test Center (NAVAIRTESTCEN), Patuxent River, MD. This presentation is unclassified.

EMP SIMULATOR TEST RESULTS FOR THE NAVY A-6E INTRUDER AIRCRAFT

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ABSTRACT

A Fleet Aircraft Assessment for Navy Testing and Analysis for EMP Limitations (FAANTAEL) electromagnetic pulse (EMP) assessment of the A-6E Intruder aircraft was conducted at the Naval Air Test Center (NAVAIRTESTCEN) TACAMO EMP Simulator (TES) facility in Patuxent River, MD, during the periods of 6/19/89 - 7/1/89 and 10/2/89 - 10/13/89. This assessment involved two fully configured A-6E aircraft. Free-field EMP testing at the TES facility and direct drive current injection testing using the TACAMO Advanced Direct Drive System (TADDS) were conducted. This test was designed to develop an EMP response baseline to quantify the margin of survivability of the A-6E. Results of this effort also support future modifications such as the A-6E Rewing Program.

This paper presents an overview of the test approach and the measured stress results by aircraft system, weapons replaceable assembly (WRA) location on the aircraft, and by measurement type.

Data presented in this paper are based on the "FAANTAEL A-6E Intruder EMP Evaluation, Quick-Look Test Summary", BDM-ABQ-89-0576-TR, and the FAANTAEL A-6E Intruder EMP Evaluation, Data Analysis Report", BDM-ABQ-89-0577-TR.

This work was sponsored by the Commander, Naval Air Test Center (NAVAIRTESTCEN), Patuxent River, MD. This presentation is unclassified.

E-6 EMP PROGRAM OVERVIEW

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Boeing is on contract to the Navy for 16 E-6 aircraft to provide a survivable communications link to the ballistic missile submarine force. The E-6 will succeed the EC-130Q aircraft.

The E-6 program began in April 1983, CDR was held in July 1985, test flights began in June 1987, an EMP qualification test was conducted in 1988, and deliveries occur from mid 1989 through mid 1991. Both FSD and production contracts are firm fixed-price.

This paper presents an overview of the E-6 EMP program.

EMP Requirement The E-6 has an EMP requirement of 32 dB hardness margin to upset on all mission essential equipment in all aircraft modes - ground alert, free flight, in-flight refueling, and in-flight trailing wire extended.

Hardening Design The E-6 has a conventional two layer aircraft hardening design consisting of hull hardening and internal cable/cabinet shielding.

Analyses The first analysis, submitted with our proposal in July 1982, was a preliminary analysis done to scope the amount of hardening necessary to meet the E-6 requirements. The second analysis, the design support analysis, refined the proposal analysis. It began at contract award and was complete at CDR. The third and last analysis, qualification analysis, is now in work.

Qualification Test A three phase 14 week EMP qualification test was conducted on the first production aircraft from 6 September through 6 December 1988 at the Naval Air Test Center (NATC). Phase 1 was an active system test, Phase 2 measured common mode core currents, and Phase 3 verified 32 dB or greater upset margins by direct drive techniques.

Production Acceptance Tests One week EMP production acceptance tests are being conducted on all other E-6 aircraft prior to delivery. These tests, subsets of the qualification test, are also conducted at NATC.

E-6 EMP TESTS

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Boeing is on contract to the Navy for 16 E-6 aircraft to provide a survivable communications link to the ballistic missile submarine force. The E-6 will succeed the EC-130Q aircraft.

The E-6 program began in April 1983, CDR was held in July 1985, test flights began in June 1987, and deliveries are scheduled from mid 1989 through mid 1991. Both FSD and production contracts are firm fixed-price.

E-6 EMP testing consists of a 14 week qualification test on the first production aircraft and one week production acceptance tests on all other E-6 aircraft prior to delivery.

The EMP qualification test was conducted on the first E-6 production aircraft (BU No. 162783) at the Naval Air Test Center (NATC) from 6 September 1988 through 6 December 1988. This three phase test verified the basic E-6 EMP requirement: 32 dB safety margins to upset for all mission essential equipment.

Phase 1, an active systems test, was conducted under the TACAMO EMP Simulator (TES). All aircraft systems, powered by engines running were operated and observed for upsets during pulsing under TES.

During Phase 2, common mode core currents were measured with the aircraft in a power off simulated power on mode, using the TES, the Navy Aircraft Vertical EMP Simulator (NAVES), and a Trailing Wire Antenna (TWA) pulser.

Phase 3 verified the 32 dB safety margin to upset requirement by increasing the measured extrapolated response waveforms by 32 dB (40 times), driving the equipment at this level with power on, and monitoring the systems for upset. The TACAMO Advanced Direct Drive System (TADDS) synthesized the extrapolated response waveforms using an arbitrary function generator and amplified them with linear amplifiers. Aircraft and mission systems were monitored for upset during and after pulsing.

EMP production acceptance tests, subsets of the qualification test, are also being conducted at NATC using the TES, TWA pulser, and TADDS. Our challenge on these tests is to complete them within the one week schedule.

E-6 EMP ANALYSES

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Two analyses have been completed and one is currently in work.

The first analysis, submitted with our proposal in July 1982, was a preliminary analysis done to scope the amount of hardening necessary to meet the E-6 32 dB safety margin to upset requirements.

The second analysis, the design support analysis, refined the proposal analysis. It began at contract award, April 1983, and with several exceptions was complete at CDR in July 1985. The mission essential equipment (MEE) were defined, circuit schematics for MEE were gathered for upset/damage threshold level determination; direct drive upset tests were run on an EC-130 aircraft for all common E-6/EC-130 common equipment to establish upset levels, and drive calculations were refined as design details were finalized.

Both upset and damage hardness margins were determined for all mission essential equipment, some 2100 equipment items, 2600 connectors, 30,000 pins. This analysis, corroborating the proposal analysis, also showed our design would meet the 32 dB upset margin requirement.

The third and last analysis, the qualification analysis, is now in work. It builds on the design support analysis. After completion of the Class III mockup in early 1986, hardening design details, particularly wiring data, become available on the Boeing WIRS (Wiring Information Release System) data base. This comprehensive data base controls wire design, manufacture, and installation for the entire Boeing commercial family of aircraft as well as the E-3, E-4, and E-6.

We have adapted the Boeing WIRS as a cornerstone of the drive calculations to be used in the E-6 EMP qualification analysis. This brings the stringent WIRS configuration control into the EMP analysis and ensures we analyze what is actually built. This dramatically improves the completeness, accuracy and efficiency of the analysis and in addition this methodology will be applicable to future Boeing military aircraft.

The qualification analysis first produced pretest predictions for the qualification test and later, in conjunction with the qualification test results, provides final verification.

E-6 ELECTROMAGNETIC PULSE LIFE-CYCLE HARDNESS ASSURANCE, MAINTENANCE AND SURVEILLANCE PROGRAM

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ABSTRACT

Nuclear survivability of the E-6 aircraft is dependent upon retention of the electromagnetic pulse (EMP) hardness designed into the aircraft. The Naval Air Test Center is tasked with implementing and monitoring the E-6 Nuclear Hardness Maintenance and Hardness Surveillance Plan. Through independent audits and evaluations of fleet maintenance actions and periodic system level tests, hardness integrity of design will be maintained throughout the operational life of the aircraft. The E-6 life-cycle hardness program will identify and correct degradations due to fleet operations and maintenance or repair activities, and monitor changes in configuration, spare part procurement and maintenance activities that may alter or negate system hardness. The independent audit will identify, document, and monitor training, maintenance and inspection procedures, configuration control, and reliability and maintainability activities that are critical to aircraft life-cycle nuclear survivability. A relational database will be developed and maintained to verify predicted and established actual failure rates of hardness critical items, support engineering investigations, and archive qualification and production acceptance test data, as well as fleet maintenance data for future system level evaluation.

ABSTRACT

E-6A FRENCH C.W TEST

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I. SYSTEM:

The French CW system has been designed to monitor any degradation in the hardness of the aircraft using reference values which were recorded and stored in memory during the initial commissioning of the aircraft.

The test set consist of:
- synthetised dual frequencies transmitter,
- synthetised dual frequencies receiver,
- special adapted sensors (electrical antenna, clamp-on probes, magnetic loops).

The French CW system is performed into separate modes:

A. GLOBAL ILLUMINATION (VHFfrequency, 80Mhz)
- verifies the electromagnetic shielding of layer 1,
- measures conducted currents, associated with both electrical and magnetic penetrations is included.

B. LOCAL ILLUMINATION (HF frequency, 2Mhz)
- verifies, detects and localizes electromagnetic leaks on joints, doors, access ports windows, and other mechanical structural penetrations.

The test equipment and specific software that is used for the measurement, storage, comparison and subsequent transfer to an accessory computer.

II. TEST CONDUCT:

On October 26, 1989, the test of the E-6A TACAMO was conduct at NATC TES facility in the following sequences:

GLOBAL ILLUMINATION :

A. The antenna was setup approximately 10 meters in front of the aircraft at the height of 4.5 meters.

1. External E-field was measured at the tip of the aircraft radome.
2. Internal E-fields were measured at three locations inside aircraft. The reference for these three fields was the external measurement.
3. Conducted current was measured on 25 test points.
4. The cargo door was opened and 25 test points were remeasured. The reference for each one was the current measured in step 3.

B. The antenna was setup 12.5 meters to the side of the tip of the aircraft radome and 45 degrees pointed at the center of the aircraft.

1. Internal field of two locations inside the aircraft was measuered.

LOCAL ILUMINATION :

1. Tip-to-tip sensor measurement was inserted into reference memory.
2. Measurements were acquired of E-field current near cargo door at 8 locations.

COMPLEX RESONANCES OF CONDUCTING POLYGONAL PLATES AND SIMPLE POLYHEDRA

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A set of electric field integral equations has been derived in the complex frequency space (SEM) for the equivalent electric currents induced on the surface of perfectly conducting polygonal plates and simple polyhedra composed of such plates. These integral equations have been solved numerically using the Method of Moments to determine the complex singularities (SEM poles) and associated spatial electric current distributions (SEM modes). SEM parameters for regular polygonal plates (triangle, square, pentagon, hexagon, octagon, etc.) are compared with those calculated for the circular conducting disk. The resonance comparisons between the plates and the disk suggest some new definitions of electrical equivalence (based, for example, on the isolated free space capacitance of each object.) Additional comparisons of the complex resonances of simple polyhedra (tetrahedron, pyramid, cube, etc.) with those of the polygonal plates which compose the polyhedra are presented and discussed.

NATURAL RESONANCES OF CONDUCTING OBLATE SPHEROIDS

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A set of combined field integral equations for the equivalent electric currents induced on the surface of a conducting body of revolution has been formulated in complex frequency space (SEM) using potential theory and the equivalence principle . The resulting equations have been discretized for numerical evaluation using the Method of Moments and rotational Fourier harmonics. The SEM poles and modes corresponding to both the internal complex resonances (cavity resonances of the conducting body) and the external complex resonances (scattering resonances of the conducting body) for perfectly conducting oblate spheroids have been calculated as a function of the spheroid eccentricities. Root locus plots of these complex resonances are presented as the spheroid changes from the degenerate case of the sphere toward the case of the vanishingly thin circular disk. Mode functions corresponding to selected complex resonances for spheroids with specific eccentricities are also presented and discussed.

ON REFLECTION AND PARTIAL CORRELATION COEFFICIENTS IN MATERIAL IDENTIFICATION

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A formulation of lattice structure models for nonhomogenuous boundaries in multilayered materials is discussed in this paper. The boundaries discussed separate media, each medium of which is assumed to be homogenuous. Autoregressive lattice models[1] of the layered material is derived from information in the reflected signal resulting from a (sin x)/x pulse incident signal onto the material. In addition, a scattering lattice model is discussed. Layer-peeling techniques[2,3] are used in identifying the reflection coefficient (S11) of each boundary. Position and dielectric constants of the material are identified.

The modeling approaches are applied to two types of data. Results of the methods are compared for simulated transmission line data. Also, results from a scattering experiment compared.

It is demonstrated that PARCORs and reflection coefficients are not synonymous quantities.

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[2] Bruckstein, A.M., B.C Levy, and T. Kailath, "Differential Methods in Inverse Scattering," SIAM J. Appl. Math., vol. 45, April 1985, pp. 312-335.

[3] Bruckstein, A.M., B.C Levy, and T. Kailath, "An Inverse Scattering Framework for Several Problems in Signal Processing," IEEE ASSP Magazine, vol. 4, January 1987, pp. 6-20.

AN ENHANCEMENT PULSE FOR RADAR TARGET DISCRIMINATION

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Very recently, Jaynes [1] presented a theory of radar target discrimination based on Bayesian probability theory. The importance of this work is that the radar target discrimination problem has, for the first time, been cast in a rigorous analytic format so that an optimum discrimination waveform, an <u>enhancement pulse</u>, can be derived. It will be shown that for the two target case the enhancement pulse will have its spectrum concentrated near the frequency where the difference in the impulse response spectrum of the two targets is a maximum.

The singularity expansion method (SEM) [2], describes a target's transient scattered fields in terms of a weighted sum of exponentially damped sinusoids in time domain, or equivalently, as a pole residue series in the complex frequency (or Laplace) domain. The enhancement pulse for optimum discrimination between two targets will be interpreted in terms of the targets' SEM parameters. Several example calculations will be presented.

[1] E. T. Jaynes,"Theory of radar target discrimination," Final report under MICOM contract DAAL03-86-D-0001, D.O. 1515.

[2] C. E. Baum, "The singularity expansion method," in *Transient Electromagnetic Fields*, L. B. Felson, Ed. New York: Springer-Verlag, 1976, ch. 3, pp. 129-179.

RADIATION OF IMPULSE-LIKE TRANSIENT FIELDS

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This paper considers the radiation of narrow pulses (impulse-like) from antennas. Beginning with the aperture formulation for antennas, the properties of a pulse radiated from such an aperture focused at infinity are discussed. This is then specialized to the case of a conical TEM feed structure combined with a reflector. This is a new method of generating an impulsive radiated field for scattering measurements.

Determination of Some Far Field Temporal Waveforms Of a Phased Array Excited by Sub-Nanosecond Pulses

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The determination of some far field temporal waveforms of a phased array excited by sub-nanosecond pulses is described. The assumptions made for this description are that each element in the array has an identical radiation pattern, that there are no mutual effects, and that the pulse length is small in comparision to the dimension of the array. Two cases will be examined. The first case will examine the relationship between the temporal waveform in the far field as a function of the angle off the boresight. The second case will examine the distortion of the temporal waveform as influenced by beam steering. The results of these analyses are presented for a unipolar and a bipolar impulse.

HARDNESS EVALUATION SYSTEM (HES) OVERVIEW

By

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The Oklahoma City Air Logistics Center (OC-ALC) Hardness Evaluation System (HES) built by EG&G is a fully integrated, EMP hardness test system. The HES contains its own drive system capable of both CW and pulse operation. In addition, the HES includes a pin tester for evaluating ESA breakdown voltage, filter insertion loss and pin continuity. An advanced minicomputer system controls the sources, acquires the resultant data and processes the data. All HES components are packaged in ruggedized, transportable containers enabling deployment to remote locations either as an entire system or only those subsystems to be used, e.g., pin tester is in its own case.

The HES contains 16 channels of fiber optic (FO) telemetry links. Active signal dividers then provide multiple outputs to drive LeCroy 6880B high-speed transient digitizers, a matrix switch for automatic routing to either Hewlett Packard 3577 network analyzers for CW acquisition or LeCroy TR8828D transient digitizers for pulse acquisition, a matrix switch for trigger source selection and a matrix switch for automatic probe connection verification.

In pulse mode, an arbitrary waveform generator drives a 20 kW peak power amplifier system. Raw data are displayed on video monitors during the automated QC process. Accepted data are processed automatically by correcting for instrumentation effects in the frequency domain. Annotated plots of both the corrected frequency domain and corrected time domain data are then automatically printed.

In CW mode, a frequency synthesizer drives a 2 kW linear power anmplifier system. Acquired data from 4 channels plus reference are corrected for instrumentation effects point-by-point and displayed on video monitors in real time. The operator may abort this process at any time. Annotated plots of both magnitude and phase responses, including transfer functions, are then automatically printed.

This work sponsored by Oklahoma City Air Logistics Center, MMETT Tinker, AFB, OK 73145

PERSONAL COMPUTER CODE FOR FAST CALCULATION OF ENERGY CONTAINED IN DIFFERENT SHAPES OF ELECTROMAGNETIC PULSE (EMP)

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Instead of wading through handbooks, monograph and hand calculations, to determine the energy developed due to EMP effects inside the front end stage of sensitive components, a simple computer code can be developed into a very fast powerful program that will take care of all needed calculations for that purpose. The program was found very useful in optimizing transient suppressor for EMP applications and was used for design of EMP hardened connectors. Short pulse wide bandwidth transients electromagnetic has been of both analytical and experimental interest for engineers involved in simulating and testing, especially in connection with nuclear electromagnetic pulse NEMP applications. Energy calculation can be tedious and time consuming. A short routine developed on personal computer significantly simplified the task.

Considerable emphasis in EMP work to develop and build simulators that can be used to measure the interaction of complex structures like airplanes, metal buildings and towers, or complex intersystem wiring, exposed to NEMP effects. Expanding of simulation methods, capability and accuracy, can provide information on NEMP induced currents and voltages that can be expected at critical points of interest within complex systems and system wiring.

This paper presents a method to use data provided by simulation or by contractor, in order to determine energy and design NEMP system hardening at the component level. In order to use this program it is assumed that the NEMP threat, voltages, currents and shapes are known, as well as the component sensitivity, and it's input load behavior. To use the program one must also know the mathematical expression of the NEMP shapes, voltages and currents. Using modern P.C. and its ability to allow mathematical calculation to be interactively linked to graphics displays, enables us to tailor the mathematical expression by using one or more expression to define the needed expression for the program. (i.e. we can use for example one mathematical expression for the rise time of an NEMP and other mathematical expression for the rest of the NEMP decay item, etc.).

One routine of the program is devoted to solving integral by using SIMPSON's rule. Another routine will be needed for calculating the energy developed on a given load, i.e., the front end of sensitive component or suppressor device. More routines will be needed to handle and manage the parameters input menu, and the graphics display of the pulse shape on the computer screen. At the time that the program is completed and running you really have a fast and strong tool in your hand.

References

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2. Dorm McCraken - Numerical Methods and Fortran Programming /P-160 N.Y. Willy 1964.
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BUILDING AN EXTRAPOLATION FUNCTION USING CALCULATED INCIDENT FIELDS

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ABSTRACT

An ideal EMP simulator would replicate the actual responses induced in a system during the detonation of a nuclear device. Present simulators can not generate the field strengths necessary to meet threat criteria. Therefore, to produce response waveforms similar to those caused by a threat environment it is necessary to extrapolate the measured data to a threat level. Extrapolation functions are calculated using the incident fields of both a threat criteria and measured fields in the simulator volume. Up to this time the total measured field response was generally used when building an extrapolation function. For simulators like the Horizontally Polarized Dipole, this total measured field is a superposition of the incident and reflected fields.

In order to build a more correct extrapolation function, it is necessary to calculate the simulator's incident field. This paper will describe the steps and numerical problems involved in calculating the incident field by mathematically combining the electrical and magnetic fields.

Extrapolation of Ground-Alert Mode Data
at Hybrid EMP Simulators

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When performing system-level EMP tests, the waveform provided by the simulator is often quite different from the desired threat waveform. In order to compensate for this difference, an extrapolation is performed. At most simulators, the extrapolation process is relatively straightforward, and it was first described by Carl Baum[1]. However, at hybrid simulators such as ATHAMAS I (also known as HPD), relatively simple techniques break down because of the presence of a strong reflected field. Therefore, new extrapolation techniques are required at hybrid EMP simulators.

In general, it is possible to take data on an aircraft configured in either ground alert mode or in free space mode. Data are then normally extrapolated to the same mode from which they are taken, although it may in principle be possible to extrapolate to the other mode. The scope of this presentation is limited to extrapolation of data taken in ground alert mode to ground alert mode with a different incident field. Although it may be possible to consider extrapolations from ground alert mode to free flight mode, or to ground alert mode with a ground whose characteristics differ from those of the simulator, this is not treated here.

In this presentation, we begin with a brief review of the existing methods for performing extrapolations, and why simple approaches break down at hybrid simulators. Next, we identify alternative approaches for hybrid simulators, and we attempt to determine their usefulness in practical situations. One technique that appears particularly promising requires the development of an "incident field" sensor. The design and performance of this sensor is the topic of another paper to be presented at this conference.

[1] C. E. Baum, Extrapolation Techniques for Interpreting the Results of Tests in EMP Simulators in Terms of EMP Criteria, Sensor and Simulation Note 222, March 20, 1977.

NOISE REDUCTION TECHNIQUES FOR FAST TRANSIENT MEASUREMENTS

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The interpretation of fast transient measurements can be significantly limited by noise from the instrumentation. Although a number of techniques are available for reducing the noise content, there is a reluctance to implement them because of the fear of obscuring important results. Consequently most investigators present raw data in their reports and use no noise reduction techniques at all.

A common approach to noise reduction is the implementation of a filter. However, it is desirable to preserve the signal in the process. With this in mind, several approaches are considered. The techniques are verified by considering simulated data with added noise. Since the signal is known, it is possible to determine the signal distortion resulting from the filter application.

Specific approaches considered include correlation controlled filters, statistic controlled filters, Wiener filter, and adaptive filters. It is shown that a significant reduction in the noise level can be achieved without appreciable distortion. In addition to the simulated data, actual measured data are also considered. In general, excellent results are obtained, indicating that noise reduction in measured data also can be accomplished without significant signal distortion.

Identification of Exponentials in Noise by SVD of the Prony Data Model

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EMP researchers seek to model and understand the transient electromagnetic signals recorded during testing. Prony's method is a technique for modeling sampled data as a linear combination of exponentials, a model often attempted in EMP research, but previously with poor results. The p-exponent discrete-time function may be concisely expressed in the form

$$\hat{x}[n] = \sum_{k=1}^{p} h_k z_k^{n-1}$$

where $h_k = A_k exp(j\theta_k)$ is the complex amplitude and $z_k = exp(\alpha_k + j2\pi f_k)$ is the *singularity* or pole location. In the case of real data samples, the exponentials occur in complex conjugate pairs, so that the model is now one of decaying sinusoids. The task is to find the order p and the parameters $\{h_k, z_k\}$ for all k. Simultaneously solving for all parameters is a difficult nonlinear problem.

The *extended Prony Method* is a suboptimum approach that effectively concentrates the nonlinearity of the model into a polynomial factoring. In the absence of noise, the extended Prony Method works very well, as we will demonstrate. With noise, however, the parameter estimates are often poor and biased, due to a lack of modeling for the noise.

One common method to overcome the bias is to over specify the number of true poles in the data, which allows the extra poles to model and account for the noise. Now the problem becomes distinguishing the poles due to the signal from those due to the noise. Three methods, as presented in Marple[1], combine to enhance the identification of the true poles: forward and backward prediction polynomials, high prediction order, and singular value decomposition (SVD).

The application of SVD provides improvement by dividing the data matrix into the *signal subspace* and the *noise subspace*. By selecting the m largest singular values, where m represents the true number of exponentials, we form a reduced rank approximation to the data matrix, which reduces the noise and effectively enhances the SNR. The Moore-Penrose pseudoinverse of the reduced data matrix then provides us with the minimum-norm least squares solution to the prediction polynomials. The result is the noise poles are much less perturbed, and the signal poles are much more apparent and closer to their true location.

We have implemented this approach in Matlab^{TM} and applied it to simulated sums of damped sinusoids and to actual transient EMP data from the *AIRBASE* database. In the noiseless case, the simulated results are excellent, and the estimates of the true parameters are still quite good even in significant noise.

For real data, we show good fit between the estimated and actual data in regions where the data actually appears to be a damped sinusoid, primarily in the decaying relaxed response region of the transient. For regions that are clearly not damped sinusoids, we still achieve useful approximations. Because the results are good for the simulated data, the fit for real data helps confirm or reject the data model of damped sinusoids.

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[1] Marple, S.L., *Digital Spectral Analysis, with Applications*, Prentice-Hall, Englewood Cliffs, New Jersey, 1987.

Segmented Processing

A method for identifying and reducing broadband noise in EMP response data

Mr. Thomas Kearns
United International Engineering

Dr. Patrick Donohoe
Mississippi State University

Mr. Stephen Langdon
WL/NTAOA

Mr. Dean Lawry
WL/NTAOA

This presentation will cover the development and status of a noise reduction technique developed for broadband response data. The technique is called "Segmented Processing" because narrow bands or "segments" of the frequency domain are analyzed and operated upon.

The segmented processing technique was developed to minimize the impact of broadband noise, particularly in extrapolated data. Segments of the frequency domain are transformed into the time domain and limited to the regions where the signal plus noise is greater than the noise. This truncated time is then transformed back into a improved estimate of the original segment.

The segmented processing technique has been demonstrated using pure and noisy analytic waveforms. A mathematical justification has also been completed. The original process was designed for manual operations and required approximately 3 minutes per 8192 point waveform. Current efforts are oriented towards automating the process based on our knowledge of the system level responses. Nominally, a six to twelve DB improvement in the high frequency noise floor is obtained.

The segmented processing approach eliminates the need for bandwidth limiting and is particularly beneficial for those programs with a bandwidth specification. Application of the segmented approach to the configuration of the acquisition digitizers will also be discussed in terms of new bandwidth specifications.

TRANSIENT ANALOG DATA FIBER OPTIC LINKS: A COMPARISON*

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Abstract

A comparison was conducted of fiber optic links for use in electromagnetic environments. Determining which link is optimum for a particular application is dependent on the electromagnetic environment's bandwidth and amplitude, the device under test, the frequency range of interest, the environmental conditions and the link's characteristics. If electromagnetic parameters, tested device and environment cannot be altered, the link must be adaptable to the device in its environment and operate over the required frequency range. The comparison determined the bandwidth, magnitude linearity versus frequency and temperature, risetime, signal-to-harmonic ratio and relative merits of each link.

*Work performed under contract for the USAF WL/NTAO.

E-3/E-6 AIRCRAFT TECHNOLOGY TRANSFER

by Dr. George Bechtold, Dennis Lynch, Dung Le, Naval Surface Warfare
Center, Code H25, White Oak,
Silver Spring, Maryland
Larry Kitchell, Mission Research Corp., 3940 East I-240,
Oklahoma City, Oklahoma

Bilateral transfer of E-3 and E-6 aircraft technology between the Navy and Air Force will be presented. This technology transfer will save the government time, money and resources.

The Air Force Logistics Command requested transfer of E-6 Hardness Assurance analytical and test data and hardness assurance design documentation, overall system and subsystem specifications for EMP, blast and thermal, and installation or engineering drawings for E-6 hardness features.

The Naval Surface Weapons Center, (NSWC) and Dual Associates, Arlington, VA complied with this request sending data and available reports on the Navy's Hardness Maintenance/Hardness Surveillance (HM/HS) efforts. NSWC has a document data base covering 20 years of aircraft EMP testing, which will be described.

An overview of Mission Research Corp. HM/HS efforts at Tinker AFB, Oklahoma City, will be presented.

Bounds for application of filter pin connectors as protective devices for RF lines

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Besides the suppression of interfering signals on transmission lines by means of filters or protection circuits respectively, the RF-transmission and reflection characteristics, caused by the insertion of filters and protection circuits, are of special significance. This presentation deals with a special kind of protective devices i. e. with filter pin connectors. As already mentioned in other publications (e.g. [1], [2]), filter pin connectors are suitable in order to realize protective devices with low weight and small volume for multi-conductor transmission lines. In this connection nonlinear filter pin connectors against transients, e.g. EMP-induced currents, should be considered. Concerning the RF-transmission and reflection characteristics for the signals there is a significant difference between nonlinear filter pin connectors and comparable conventional nonlinear components as e.g. suppressor diodes. In case of filter pin connectors these RF-characteristics are essentially influenced by the ground connections and ground conditions inside the plugs which contain the filter pins.

Be means of measurement results the influence of the ground conditions on the RF-transmission and reflection characteristics in connection with filter pin connectors will be shown and discussed.

References

[1] L.A. Krantz: "EMI/EMP-the connector solution" Int. Aerospace and Ground Conf. on Lightning and Static Electricity, Dayton, Ohio, June 24-26, 1986

[2] J.L. ter Haseborg,: K.-D. Kruse, F. Wwolf "Transmission characteristics of nonlinear EMC-protection circuits consisting of filter pin connectors", Int. Symp. on EMC, Nagoya, Japan, Sept. 8-10, 1989

APPLICATION OF NORM ATTRIBUTES FOR ELECTRONIC SURGE ARRESTOR FAILURE IDENTIFICATION

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ABSTRACT

Residual stress norm attributes are proposed for use as acceptance criteria for High Altitude Electromagnetic Pulse (HEMP) hardness certification. The application of these norms to hardness surveillance (HS) has not been formally addressed. However, it would be beneficial if acceptance criteria data could provide baseline HS requirements. In order to achieve this objective, the relation between POE failure modes and norm values needs to be established.

During the summer of 1989, test data were obtained on 670 electrical surge arrestors (ESA's) that have been fielded for up to 10 years with no hardness maintenance (HM) or hardness surveillance (HS) activity. Each ESA contains a spark gap, inductor, and bidirectional Zener diode in a Pi configuration. The presence of nonlinear ESA devices raises questions as to the utility and validity of using norms for HS activities.

The test data were separated into pass/fail bins based on observation of the ESA output. The ESA failure rate function was determined, and probability distribution functions were computed for each norm. The probability of detecting a failed ESA and the probability of false alarm were determined based on the distribution functions. Comparison with the experimental data yields excellent results and clearly identifies those norms which lead to a high probability of failure detection with a low probability of false alarm.

Experimental Results for Protection Module

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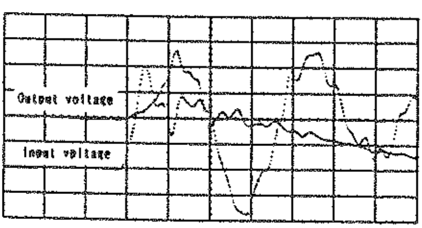
EMP induces very first transients on for example exposed lines. These transients have sub-microsecond rise time. There is definitely a threat to electronic equipment. Transient suppression devices (filters, nonlinear devices, gap, etc.) have been in use to provide protection against transients like lightning and EMI. Each suppression device has definite a function and can't reduce very first transients enough by itself. The sufficient protection against such transients requires a hybrid type protection module.

This time, the protection module (for AC 100V 7.5kVA power line) was made on experimental basis. The module was tested to evaluate it's performance. Tabel 1. shows test conditions and test results. Figure 1. shows typical oscillograms.

Table.1 Test condition and result.

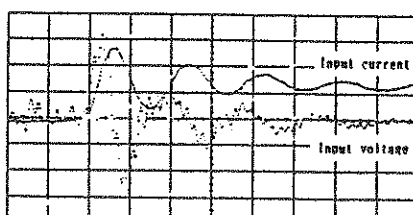
Test No.	input waveform		output
	rise time	peak value	voltage
1	5 ns	80 kV	2000 V
2	0.5 μs	500 kV	600 V
3	0.3 μs	1 kA	200 V
4	1 μs	10 kA	200 V

(1) Test No.1



10ns/div 20kV/div 550V/div

(2) Test No.2



500ns/div 160kV/div 2.2kA/div

Fig.1 Typical oscillograms.

A NANOSECOND TIME-BASED GAS TUBE MODEL

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The Boeing Company
P.O. Box 3999 - Mail Stop 17-01
Seattle, Washington 98124-2499

A nonlinear electrical gas tube model valid in the nanosecond time range has been developed. It operates on Micro-Cap III (Spectrum Software) and executes in about 10 seconds on a 80286 processor based personal computer.

The nonlinear model is based on two nonlinear equations, one for the gas temperature, and one for the gas conductivity. Sources for the equations are functions of the voltage across the tube, and the instantaneous, dissipated power in the tube.

The Navy/Boeing E-6 aircraft electronic support measures (ESM) system is EMP protected by a fast acting preionized gas tube placed just behind the antenna. The model is being used to verify that the required 32 dB safety margin is met for the susceptible components in the ESM receiver.

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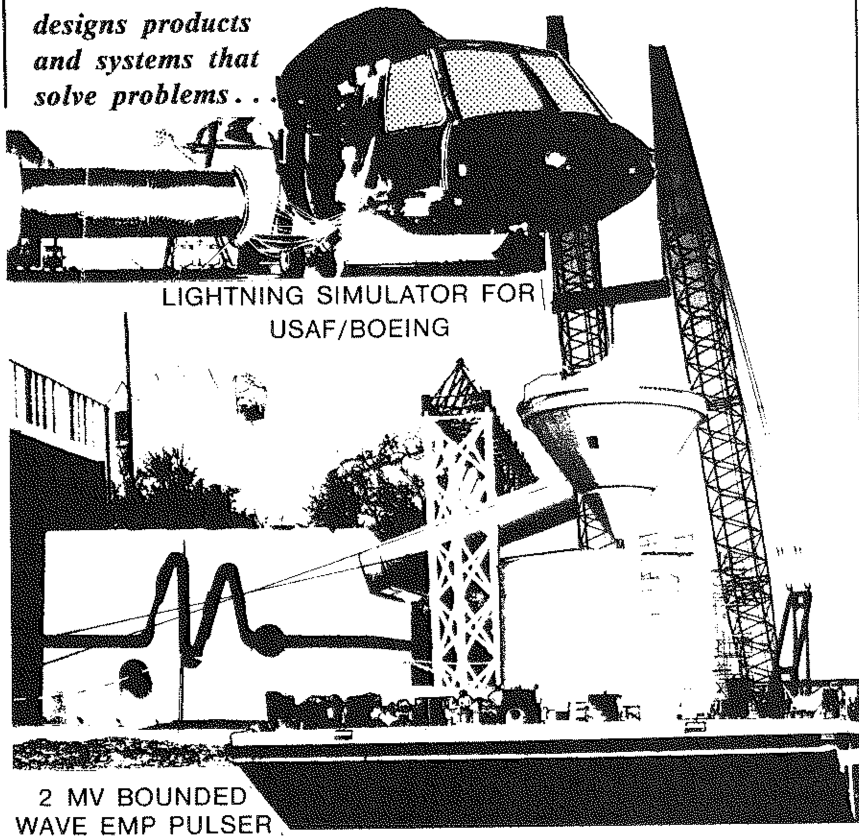

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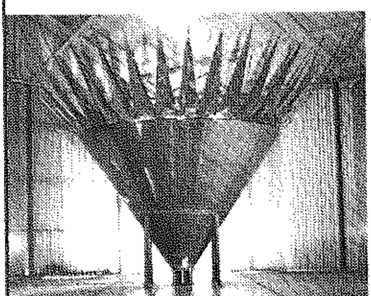
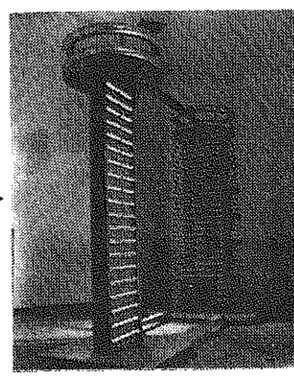
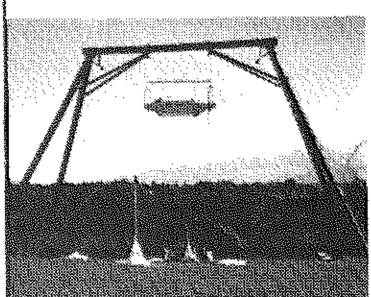


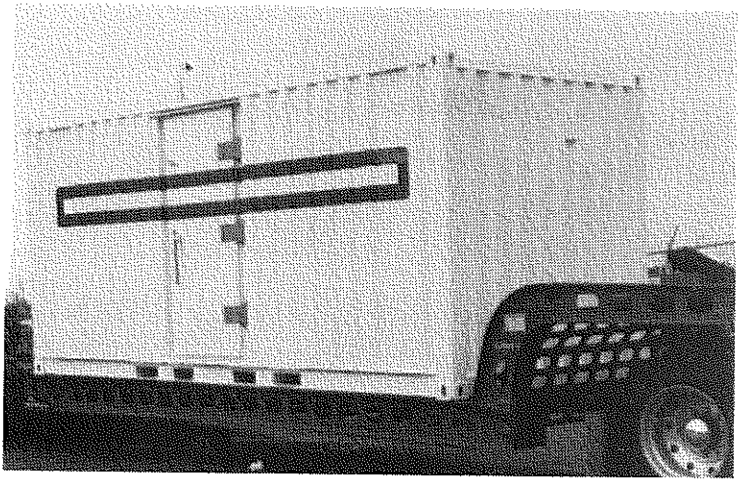
1 MV ultra-fast risetime EMP generator.

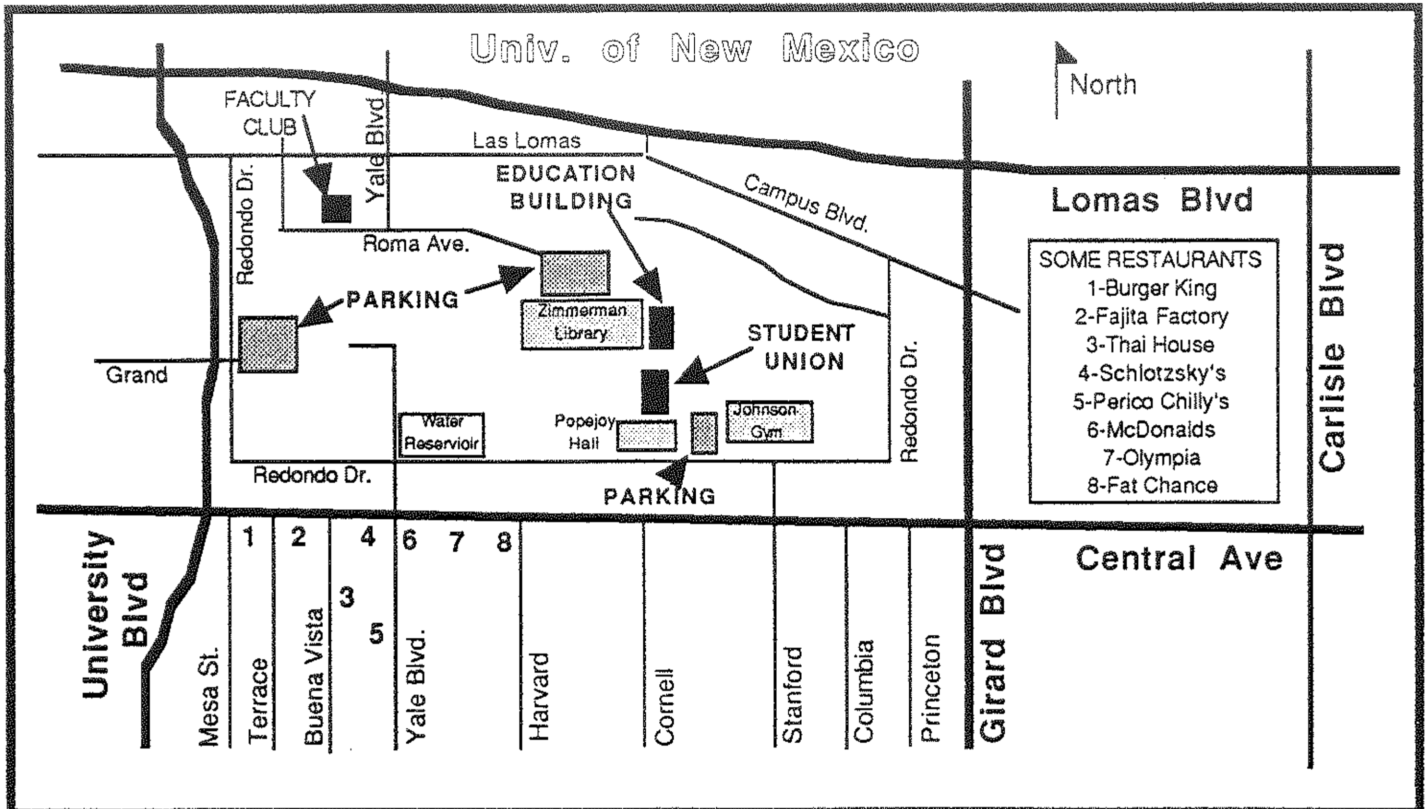


2 MV lightning simulator.



5 MV horizontally polarized EMP generator.





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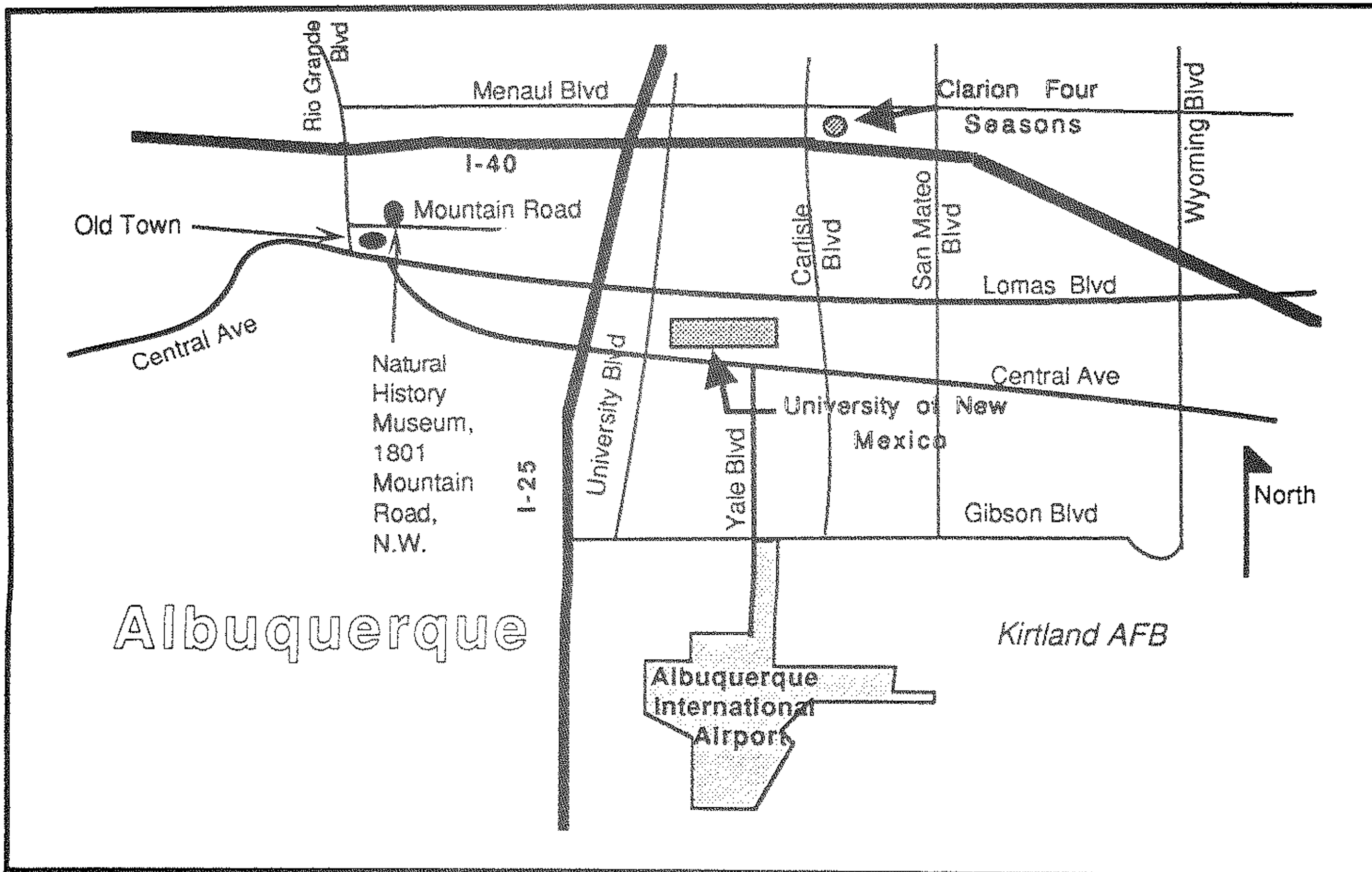
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