NEM 1984

FOURTH NEM SYMPOSIUM JULY 2-6, 1984

IN

Baltimore

DURING MARYLAND'S
350th ANNIVERSARY

SPONSORED BY THE PERMANENT NEM COMMITTEE

URSI

1884 1984

SUMMA FOUNDATION

TECHNICAL PROGRAM SUMMARY

JULY 1984 NEM MEETING

HILTON HOTEL, BALTIMORE, MARYLAND

LOCATION	MONDAY JULY 2 9:00-12:00	MONDAY JULY 2 1:30-5:00	TUESDAY JULY 3 9:00-12:00	TUESDAY JULY 3 1:30-5:00	WEDNESDAY JULY 4	THURSDAY JULY 5 8:30-12:00	THURSDAY JULY 5 1:30-5:00	FRIDAY JULY 6 8:30-12:00	FRIDAY JULY 6 1:30-5:00
F.S.K. CENTER	A PLENARY SESSION		C PLENARY SESSION		HOLIDAY				
F.S.K. SOUTH		B1 THEORY I		D1 THEORY II	SOCIAL BOAT TRIP	E1 THEORY III	F1 CABLES AND TRANSMISSION LINES	G1 SIGNAL PROCESSING AND DATA ANALYSIS	H1 EQUIPMENT ASSESSMENT
CARROL		B2 EM STANDARDS AND SPECIFICATIONS		D2 SYSTEM HARDNESS ASSESSMENT		E2 AIRCRAFT	F2 COMMUNICATIONS FACILITIES	G2 SIMULATION AND SYSTEM TESTING	H2 HARDNESS AND PROTECTION MAINTENANCE
HANOVER ROOM		B3 LIGHTNING		D3 LIGHTNING AND EMP		E3 SREMP AND SGEMP	F3 SENSORS AND INSTRUMENTATION	G3 CABLE TESTING	
		NIGHT AT THE AQUARIUM 7:00 - 11:00		COCKTAIL HOUR AND BANQUET	FIREWORKS				

WELCOME TO BALTIMORE

On behalf of the 1984 NEM Conference Committees and the cooperating technical societies and organizations I should like to extend a hearty welcome to all of the conference participants and also their families and their guests who have accompanied them to Baltimore.

A special word of thanks is due each of the members of the committees. Through their patient efforts the technical program for NEM 84 should prove to be very enriching for everyone from the neophyte to the experienced EMP practitioner. They have contrived to bring together for this conference papers covering the history and scope of EMP including overlap areas with related hardening disciplines. All of this has been integrated together into a meaningful whole. The technical depth in most areas has been reinforced quite generously with the aid of tutorial review papers.

Additional expression of gratitude is due the committee members for the opportunities they have arranged for the conference attendees to interact socially. Among these events are the get-together on Monday evening, July 2, at the National Aquarium of Baltimore, the conference banquet on Tuesday evening, July 3 and the "official" boat trip on Wednesday July 4.

This year, 1984, is the centennial of the IEEE and the 350-th anniversary of Maryland. We trust than NEM 84' shall prove to be a memorable occasion.

Dr. Louis F. Libelo
Conference Chairman

NEM 84

NEM 84 is sponsored by the "Permanent NEM Committee" in cooperation with the following organizations:

IEEE Antennas and Propagation Society

IEEE Electromagnetic Compatibility Society

US National Committee of the International Union of Radio Science (USNC/URSI)

Commission B: Fields and Waves

Commission E: Interference Environment

Electromagnetic Society

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PLENARY SESSION A
F. K. Center
Chairman: Dr. J. N. Bombardt
Army Electronic Research and Development Command
Harry Diamond Laboratories, Adelphi, MD

9:00 Welcoming Address

9:30 THE HISTORY AND PHYSICS OF EMP, Dr. Conrad Longmire, Mission Research Corporation, Santa Barbara, CA

10:30 EMP EFFECTS ON SYSTEMS AND HARDENING APPROACHES, Dr. William Karzas, R&D Associates, Marina del Rey, CA

11:15 EMP SIMULATORS-THEIR CAPABILITIES AND LIMITATIONS, Dr. Clifford Giles, EG&G, Washington Analytical Services Center, Inc., Albuquerque, NM

SESSION B1
THEORY I
F. S. K. South
Chairman: Dr. E. K. Miller
Lawrence Livermore National Laboratories
Livermore, CA

1. 1:30 INVITED PAPER: ELECTROMAGNETIC SHIELDING TOPOLOGY: AN OVERVIEW, Fred Tesche, LuTech, Inc., Hayward, CA

2. 2:05 EXCITATION OF A CIRCULAR LOOP THROUGH A SMALL APERTURE, H. Yatom, R. Ruppin, Soreq Nuclear Research Center, Yavne, Israel

3. 2:30 NUMERICAL CALCULATION OF EMP COUPLING THROUGH LARGE APERTURES, R. Holland, and D. Merewether, Electro Magnetic Applications, Inc., Albuquerque, NM, and P. Parhami, TRW Inc., Redondo Beach, CA

4. 3:15 APERTURE COUPLING PHENOMENOLOGY: A STUDY OF THE ANALYTICAL SOLUTIONS TO E- AND H-POLARIZED SLIT CYLINDER PROBLEMS, R. Ziolkowski and B. Grant, Lawrence Livermore National Laboratories, Livermore, CA

5. 3:40 ELECTROMAGNETIC FIELD COMPUTATION FOR A CONICAL PLATE TRANSMISSION LINE TYPE OF EMP SIMULATOR, T. Brown, Dikewood, Albuquerque, NM, D. Giri, LuTech, Inc., Hayward, CA, and H. Schilling, WWDBw Munster, Federal Republic of Germany

6. 4:05 EMP COUPLING TO A RECESSED, THIN PLATE IN A RECTANGULAR WAVEGIUDE, K. Knight, Rockwell International Corporation, Lakewood, CA

7. 4:30 NUMERICAL PROPAGATION OF LOCALIZED PULSES IN FREE SPACE AND IN CONDUCTING MEDIA, E. Marx, National Bureau of Standards, Gaithersburg, MD

ELECTROMAGNETIC SHIELDING TOPOLOGY: AN OVERVIEW

by

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ABSTRACT

The hardening of complex electrical systems can be accomplished through a number of different approaches. One involves developing one or more electromagnetic barriers (or shields) surrounding sensitive components, and then limiting the number and types of penetrations through the barriers.

As a result of applying electromagnetic analysis techniques to systems shielded in this manner, several design guidelines based on topological concepts have evolved. When these principles are adhered to during the design and construction phase, the shielding integrity of a system can be made more reliable.

This paper reviews the concept of the electromagnetic topological diagram, and the associated interaction sequence diagram for an electrical system. Various design guidelines are introduced, and the use of the interaction sequence diagram in estimating the response of the system to an external electromagnetic excitation is discussed.

EXCITATION OF A CIRCULAR LOOP THROUGH A SMALL APERTURE

H. Yatom and R. Ruppin

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The problem of determining the current excited on a circular loop which is placed opposite a small circular aperture in a conducting screen, on which an electromagnetic plane wave is incident, is considered. It is shown that this geometry is unusual in that the resulting integro-differential equation can be reduced to an explicit expression for the current. The total rate of electromagnetic energy flow in the radiation zone is also calculated, as is the angular dependence of the energy flux. Sample results are presented, which demonstrate the resonant behavior of the system when the wavelength of the incident wave is equal to the loop circumference.

NUMERICAL CALCULATION OF EMP COUPLING THROUGH LARGE APERTURES

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Parviz Parhami, Ph.D
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This paper presents a technique for calculating free-field EMP coupling through an electrically large aperture into a cavity. The specific problem we address is EMP excitation of an airplane cockpit by coupling through the windows or bubble. Our basic technique uses a time-domain finite differencing (TDFD). Initially, the electromagnetic fields in the vicinity of the aircraft are partitioned into an incident part (E^i, H^i) which is known and a scattered part (E^s, H^s) which is determined by TDFD. The scattered fields (E^s, H^s) are first evaluated with the aperture foiled over by a perfectly conducting sheet. We refer to this TDFD calculation of (E^s, H^s) as the first pass. The electric surface current density on the foil as computed during the first pass is stored at each mesh point for subsequent use.

Let us now consider what happens if the cover foil is removed from the aperture. Physically, the electromagnetic fields will undergo a perturbation which we call (E^p, H^p). The total field outside the aircraft becomes the sum of the incident, scattered and perturbation fields, $(E^T, H^T) = (E^i + E^s + E^p, H^i + H^s + H^p)$. The same is true inside the cavity, except that (E^i, H^i) and (E^s, H^s) exactly cancel before the aperture is unfoiled, so that total field inside the cavity is just (E^p, H^p).

We here refer to the evaluation of (E^p, H^p) as the second-pass calculation. This calculation is also done by TDFD. In particular, it has been demonstrated that (E^p, H^p) is exactly the field which the electric surface current on the aperture foil generates if the foil is removed but its surface current is left behind to flow in free space across the open aperture. Since this surface current was computed and stored during the first pass, it is available for recall as the input driving function of the second-pass calculation.

For the second pass, it is obviously desirable to mesh the cockpit/aperture and resolve the internal fields much more finely than was done for the first pass. This desire raises the question, however, of how much the external aircraft geometry must be retained for the second-pass calculation. The chief message of this paper is that astonishingly little of the overall airplane exterior must be retained. A single cell around the perimeter of the aperture and over the volume of the cockpit gives second-pass results which differ only by 10% from second-pass calculations made with the entire external aircraft retained. In conclusion, the results of this exercise have been compared with cockpit measurements obtained during a recent aircraft test program and presented in this paper.

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[1]Merewether, D. E. and R. Fisher, IEEE Trans. Electromag. Compat., vol. EMC-24, November 1982, pp. 406-410.

APERTURE COUPLING PHENOMENOLOGY: A STUDY OF THE ANALYTICAL SOLUTIONS TO E- AND H-POLARIZED SLIT CYLINDER PROBLEMS*

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The coupling of an electromagnetic wave through an aperture into an enclosed region is a fundamental issue in many EMP studies. Until recently, however, analytical solutions have not been available and purely numerical techniques encounter difficulties largely due to the edge of the aperture. Parameter studies of analytical solutions to one or more coupling problems would greatly enhance our understanding of the coupling process and would lead to general "rules of thumb" which would enable one to estimate, for engineering analysis and design purposes, the coupling into more generally shaped cavities via more generally shaped apertures.

A newly developed approach (1) based upon N-series and Riemann-Hilbert problem techniques has made it possible to obtain analytical solutions to families of canonical problems descriptive of the electromagnetic coupling problem. In particular, the generalized dual series approach has led to the solution of the problem of an H-polarized plane wave scattering from an infinite circular cylinder with an infinite axial slot enclosing a concentric impedance surface (2) and more recently, to the E-polarized plane wave version of this problem. These solutions accommodate arbitrary angles of incidence and cylinders and apertures that are small or large in wavelengths, and they encompass the case of a slit cylinder enclosing a thin or thick concentric wire as well as an empty slit cylinder.

Results of parameter studies of the solutions to these canonical slit cylinder problems will be reported. For instance, axial currents along an interior wire in the E-polarized case and aperture electric field strengths in the H-polarized case as functions of wavelength for various aperture and wire sizes will be given. Moreover, the coupling process in the E- and H-polarized plane wave problems will be characterized and compared. Preliminary investigations have demonstrated substantial differences between the two cases.

(1) R. W. Ziolkowski, "N-Series Problems and the Coupling of Electromagnetic Waves to Apertures: A Riemann-Hilbert Approach", UCRL-88906, Lawrence Livermore National Laboratory, Livermore, CA, 1983 (to appear in SIAM J. Math. Anal.).

(2) W. A. Johnson and R. W. Ziolkowski, "The Scattering of an H-Polarized Plane Wave from an Axially Slotted Infinite Cylinder: A Dual Series Approach", UCRL-88829, Lawrence Livermore National Laboratory, Livermore, CA, 1983 (to appear in Radio Science).

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

ELECTROMAGNETIC FIELD COMPUTATION FOR A CONICAL PLATE TRANSMISSION LINE TYPE OF EMP SIMULATOR

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H. Schilling, WWDBw, Munster, Germany

ABSTRACT

A conical plate transmission line type of EMP simulator is operational in WWDBw, Munster, Germany. In the context of this facility, the present paper deals with the computation of the characteristic impedance of the spherical TEM mode of propagation and electromagnetic field components at specified test points of the facility. It is observed that the impedance and field analyses are available in References 1 and 2. Apposite computer programs were written for the computations and the results compared with available measurements. The numerical approach uses a Newton-Raphson's method for finding zeros of complex analytic-transcendental functions. The correlation of measured fields to calculated fields is excellent for the principal field componenets, but only fair for the other field components. Detailed comparisons, along with suspected reasons for deviations, will be presented. These comparisons include correlation of calculations and measurement in prescribed transverse planes, as well as along the approximate direction of wave propagation.

References

1. F.C. Yang and K.S.H. Lee, "Impedance on a Two-Conical-Plate Transmission Line," Sensor and Simulation Note 221, Air Force Weapons Laboratory, Kirtland AFB, NM, November 1976.

2. F.C. Yang and L.O.O. Marin, "Field Distribution on a Two-Conical Plate and a Curved Cylindrical-Plate Transmission Line," Sensor and Simulation Note 229, Air Force Weapons Laboratory, Kirtland AFB, NM, September 1977.

EMP COUPLING TO A RECESSED, THIN PLATE IN A RECTANGULAR WAVEGUIDE

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ABSTRACT

The coupling of specified EMP source fields in the aperture of a rectangular waveguide to a recessed, thin plate that forms a central coaxial element is analyzed. The problem bears certain similarities to the bifurcated waveguide problem, but differs from it in that the analyzed configuration supports open waveguide modes over part of its extent, and TEM and higher coaxial waveguide modes over the remainder. Another departure is that the frequency spectrum of the source field is below cut-off, so that no propagating modes exist in the open waveguide section.

Expressions for the potential induced across the coaxial section are given in terms of the dominant open waveguide modes H_{01}, E_{11} induced by the source field.

NUMERICAL PROPAGATION OF LOCALIZED PULSES IN FREE SPACE AND IN CONDUCTING MEDIA

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A plane-wave pulse propagates in free space without changing shape, so that the determination of the pulse from the initial fields is trivial. When the pulse is localized, the shape changes as the pulse propagates, and the fields at a time t have to be obtained from the initial fields with the help of the Green function for the scalar wave equation. The resulting integrals over the information-collecting sphere centered at the field point and of radius ct are carried out numerically for pulses that are essentially gaussian in x and y, and a double exponential in z. Other shapes of the initial pulse can be substituted, and the fields can be given analytically or numerically as long as the appropriate derivatives can be computed. The integration can be restricted to the intersection of the sphere with the region where the initial fields differ significantly from zero. The initial fields have to be solenoidal, and they are constructed so that they propagate mainly in the +z-direction. When the pulse propagates in a conducting medium, the fields at time t can still be computed from their initial values, although D has to be specified instead of E. The Green function now contains a damping factor and a time integral has to be carried out because the Green function no longer is confined to the forward light cone. These free fields have to be computed to represent the incident fields in a transient scattering problem. From the incident fields and the properties of the scatterer, surface fields can be determined by solving an integral equation by means of the stepping-in-time procedure. The scattered fields can then be determined from the surface fields by integrations.

SESSION B2
EM STANDARDS AND SPECIFICATIONS
Carrol Room
Chairman: E. Vance
SRI International, Menlo Park, CA

1. 1:30 INVITED PAPER: HAMS EMP HARDNESS SURVEILLANCE AND MAINTENANCE TECHNIQUES, G.E. Morgan, Rockwell International Corporation, Anaheim, CA

2. 2:05 A FORTRAN 77 BASED DATA ACQUISITION SYSTEM FOR SUPPORT OF NUCLEAR WEAPONS EFFECTS TESTING, C. Hansen, J. Hardy, J. Corcoran, and R. Himes, BDM Corporation, Albuquerque, NM

3. 2:30 DEVELOPING STANDARDS FOR EMP HARDENING, E. Vance, W. Graf, and J. Hamm, SRI International, Menlo Park, CA

4. 3:15 SPECIFICATION OF ELECTROMAGNETICALLY INDUCED STRESS AND FAILURE THRESHOLD TO IMPROVE SYSTEM RELIABILITY, W. Kehrer, and J. Castillo, R&D Associates, Albuquerque, NM

5. 3:40 EMP SPECIFICATION AND HARDENING OF THE B-1B AIRCRAFT, J. Yu, Rockwell International Corporation, Lakewood, CA

6. 4:05 INTEGRATION OF EMP AND OTHER ELECTROMAGNETIC STANDARDS AND SPECIFICATIONS, W. Graf, E. Vance, SRI International, Menlo Park, CA

HAMS EMP HARDNESS SURVEILLANCE AND MAINTENANCE TECHNIQUES*

G. E. Morgan

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The nuclear EMP-hardening technology is unique among the engineering disciplines in that there is no inherent feedback on performance in peacetime (no EMP events occur). For this reason, the demand for special hardness measurement techniques and maintenance procedures is critical. Various techniques are described, but particularly some of the Hardness Assurance Monitor System (HAMS) concepts are outlined.

The method used for monitoring, and maintaining, EMP hardness depends partly on the approach selected for EMP protection. If the EMP immunity is achieved by individual protection of all the pieces, then the monitoring will tend to focus on those particular elements. The difficulties here lie (1) in gaining access to all of the hardened components for test, and (2) in never knowing for certain the impact of individual part failures (or combinations) on overall survivability, except by criteria-level tests.

For those systems which achieve the desired EMP protection by providing an impervious overall electromagnetic shield, the hardness assurance, surveillance and maintenance becomes much easier and faster, and probably more reliable. Existing MIL-Specs for measuring EMP shielding-effectiveness are not valid for EMP, but several HAMS techniques are available and are described. A HAMS system which is built in and automated can perform periodic tests unattended, with minimal labor expended to assure survival. Fault isolation (location) techniques can also make maintenance repairs faster and more certain.

*Work on various HAMS techniques have been funded by AFWL, DNA, ESD, NAVAIR, and NSWC but none of these are specifically referenced in this paper.

A FORTRAN 77 BASED DATA ACQUISITION SYSTEM FOR SUPPORT OF NUCLEAR WEAPONS EFFECTS TESTING

C. HANSEN, J. HARDY, J. CORCORAN, R. HIMES

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This paper describes the implementation and application of a FORTRAN 77 fast transient data acquisition system for support of nuclear weapons effects testing. This system has been installed at several DNA and AFWL EMP and pulsed power test sites. The software provides support for a wide variety of instrumentation types, including both IEEE 488 and CAMAC digitizers. A data dictionary data base approach was used to allow the system to be configured for individual test sites with little or no code modification. The development of the system using a standard high-level language (FORTRAN 77) provides more flexibility for future enhancements and allows for the potential adaptation to different computer hardware environments.

This paper will discuss the following major topics:

(1) Design philosophy
(2) Instrumentation support capabilities
(3) Use in support of EMP and pulsed power testing
(4) Adaptability for different hardware environments
(5) Potential enhancements and future applications

The software was developed for the Air Force Weapons Laboratory and the Defense Nuclear Agency under Contract F29601-82-C-0030.

DEVELOPING STANDARDS FOR EMP HARDENING

E. F. Vance, W. Graf, and J. M. Hamm
SRI International
Menlo Park, California

Several factors influence the development of standards for hardening systems against the EMP. These standards must allow one to characterize the performance required of a hard system without regard to the method used to achieve that performance, and to develop a measure of that performance that does not depend on how the performance is achieved.

We begin by defining the attributes of a hardened system; those features that distinguish a hardened system from one that is not hardened. Fundamentally, the EMP-induced transient stress at each point inside a hardened system is less than the transient tolerance of that point. For this criterion to be useful, these points must be grouped inside certain volumes. Thus, we can state that the EMP-induced stress must be less than the transient tolerance everywhere inside these volumes.

When the points are grouped into volumes, it is presumed that we can determine (or infer) that the stress inside the volume is smaller than the transient tolerance of the volume, point by point. If the volume is inside the system-level EMP barrier, this "test of hardness" can be done by determining that (1) the barrier is sufficiently effective so that no EMP-induced stress inside the barrier can exceed the tolerance of any system element inside the barrier (i.e., the largest stress is less than the smallest tolerance), or (2) the EMP-induced stress applied to each subvolume is less than the tolerance of the subvolume, and that for each point outside the subvolumes, the stress is less than the tolerance, point by point. The first part of the second method is basically the approach of determining that the stress at the terminals of each box is less than the tolerance of the box. Note, however, that the box measurements alone are not sufficient; the stress-tolerance condition must also be demonstrated for all points outside the boxes (but inside the system).

In addition, standardization will require an unambiguous definition of transient stress and tolerance, as well as the determination of the transient tolerance on internal equipment and hardware.

SPECIFICATION OF ELECTROMAGNETICALLY INDUCED STRESS AND FAILURE THRESHOLD TO IMPROVE SYSTEM RELIABILITY

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To insure that a system retains a high level of reliability throughout exposure to EM induced stresses such as EMP, lightning, EMC and other effects, it would be valuable to have specifications which define stress and the susceptibility level of electronic boxes. The wide range of frequencies and associated pulse shapes together with the complexity of coupling of fields to systems makes it difficult to formulate a stress specification which encompasses all induced effects. The complexity of system configurations and conditions of illumination results in large uncertainties in stress which in turn generates a need for large safety margins. A similar problem exists for specifying the susceptibility of electronic subsystems. Modern electronic systems are highly complex and there are extensive interactions between subsystems. This makes prediction of failure extremely difficult. It is highly desirable to develop a test standard which can be implemented in the laboratory to establish a susceptibility level for electronic boxes. However, the uncertainties associated with defining failure modes for complex systems and the difficulty in identifying the test parameters necessary to characterize failures, have thus far prevented the development of a comprehensive test standard.

The various types of specifications will be identified and the relationship between a specification and system EMP hardness is discussed. The key factors for each different specification type will be defined. Finally, examples of different specifications are given.

EMP SPECIFICATIONS AND HARDENING OF THE B-1B AIRCRAFT

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Presented in this paper is a summary of how EMP specifications and hardening have been achieved in the B-1B aircraft. It begins with the fundamental external field requirement specified for the B-1 system, and traces the development and implementation of the lower-tiered requirements from the initial design to a fully developed production aircraft. The result is a hardened design with both system level and equipment level hardness addressed. Four areas of interest are emphasized: EMP requirements, design solutions, hardening implementation, and a highlight of EMP lessons learned in the B-1 program.

The discussion of EMP requirements includes an account of how the EMP specification was developed for shielding and equipment. It begins with the initial design phase of the B-1A. Results of developmental aircraft EMP response analyses and tests are summarized. These analyses and test results directly impacted the EMP hardening approach chosen, and specification requirements developed. The set of EMP hardening requirements developed jointly between the customer and the contractor is provided. These design requirements were specified for equipment and system shielding elements.

Next, EMP design solutions employed in the B-1B are reviewed. These represent design techniques used to achieve the EMP requirements, especially in shielding, such as fabrication of joints, bay door seals, cable shields, and connector improvements. Other EM practices and requirements such as EMIC, installation, and bonding, which complement EMP hardening design, are also addressed.

The discussion of hardening implementation briefly accounts for the flow of EMP requirements from the customer to contractor and contractor to supplier, and the necessary interfaces involved.

Finally, EMP lessons learned in the B-1 program such as consideration of hardening in the early design, hardening and maintainability considerations, hardness requirements integrated with other design requirements, and close interface among customer, contractor, and suppliers, are provided as a hindsight that may serve as a guide for similar programs.

INTEGRATION OF EMP AND OTHER ELECTROMAGNETIC STANDARDS AND SPECIFICATIONS

W. Graf and E. F. Vance
SRI International
Menlo Park, California

Historically, EMP requirements have been perceived to be substantially different from, and in many cases conflicting with, other electromagnetic requirements. As a result, hardening a system against the effects of EMP has frequently been credited with a substantial increase in total system cost, as well as with technical difficulties in accommodating conflicting requirements. Although many source parameters are different (in areas such as EMI/EMC, communication security, and EMP hardening), the fundamental aspects of dealing with these electromagnetic requirements are really the same. Invariably, it is desired to reduce the interaction of a source of interference with a receptor, whose function is impeded by the interfering source. Therefore, different methods used to reduce the interaction of a source and receptor ought at least not to conflict with each other, and an argument can be made that an integrated approach to EMP and other electromagnetic requirements is not only feasible, but will ultimately result in better overall system performance at a lower cost.

As an example, consider the grounding requirements that often appear to conflict with each other. A single-point signal ground is often specified in a large system, resulting in ground conductors that penetrate electromagnetic barriers. To harden such a system against the effects of EMP, a treatment would be required at each such penetration (filter or surge arrester), resulting in increased cost and lower reliability. Yet, from a topological point of view, a compatible solution is simply to terminate the ground conductor on each side of the barrier, and not allow the penetration. Not only are the extra components required for EMP hardness eliminated, but the system performance in peacetime is often improved as well, because the grounding network in a large system can act as an effective interference distribution network. Note that at dc and powerline frequencies the compatible technique is no different from the traditional one; thus, it automatically satisfies safety and other low-frequency requirements. However, at higher frequencies, the different volumes are effectively decoupled, at least as far as the grounding conductors are concerned. This decoupling is desirable for EMP hardness, as well as other interference requirements, including communication security.

Although integration of EMP and other electromagnetic standards and specifications is desirable from a technical and economical viewpoint, historical objections to new techniques must be overcome to implement a unified approach to electromagnetic requirements.

SESSION B3
LIGHTNING
Hanover Room
Chairman: Dr. D. Levine
Goddard Space Flight Center, Beltsville, MD

1. 1:30 INVITED PAPER: LOCATION OF LIGHTNING ELECTROMAGNETIC SOURCES BY TIME OF ARRIVAL COMPARED TO INFERENCE FROM ELECTROMAGNETIC FIELDS, THUNDER ACOUSTICS, AND VIDEOTAPE PHOTOGRAPHS, C. Baum, and J. O'Neill, Air Force Weapons Laboratory, Kirtland AFB, NM, and E. Breen, D. Hall, and C. Moore, New Mexico Institute of Mining and Technology, Socorro, NM

2. 2:05 THE ROCKET-TRIGGERED LIGHTNING PROGRAM: 1983 RESULTS, R. Richmond, Wright Aeronautical Laboratory, Wright Patterson AFB, OH

3. 2:30 THE WAVEFORMS OF LIGHTNING RADIATION FIELDS, E. Krider and C. Weidman, University of Arizona, Tucson, AZ

4. 3:15 NATURAL FREQUENCIES OF A POST WITH A LIGHTNING RETURN STROKE ATTACHED, F. Yang, and K. Lee, Dikewood, Santa Monica, CA

5. 3:40 RETURN-STOKE TRANSMISSION-LINE MODEL, L. Baker, Mission Research Corporation, Albuquerque, NM

6. 4:05 MODEL FOR LIGHTNING RETURN STROKE WITH CORONA, C. Baum, Air Force Weapons Laboratory, Kirtland AFB, NM, and L. Baker, Mission Research Corporation, Albuquerque, NM

7. 4:30 CALCULATED TEMPERATURE AND BRIGHTNESS OF A LIGHTNING DISCHARGE, R. Gardner, A. Paxton, and L. Baker, Misson Research Corporation, Albuquerque, NM

8. 4:55 EXPERIMENTAL DETERMINATION OF OPTIMAL SENSOR LOCATION ON AIRCRAFT FOR TRANSIENT ELECTROMAGNETIC MEASUREMENTS, V. Liepa and S. Pennock, University of Michigan, Ann Arbor, MI

LOCATION OF LIGHTNING ELECTROMAGNETIC SOURCES BY TIME OF ARRIVAL COMPARED TO INFERENCE FROM ELECTROMAGNETIC FIELDS, THUNDER ACOUSTICS, AND VIDEOTAPE PHOTOGRAPHS

C. E. Baum and J. P. O'Neill
Air Force Weapons Laboratory

E. L. Breen, D. L. Hall, and C. B. Moore
New Mexico Institute of Mining and Technology

Abstract

This paper presents data on lightning electromagnetic source location by a time-of-arrival system. The time-of-arrival locations are compared to locations obtained from the lightning electromagnetic fields, a whole-sky camera, and locations obtained from the time-of-arrival of thunder acoustic sources at a microphone array. The electromagnetic fields presented are from leader and return stroke sequences within each lightning flash.

The data were obtained during the summer of 1981 from rocket triggered and natural lightning flashes. The data were recorded in a shielded underground instrumentation room, the Kiva, on South Baldy Peak in the Magdalena Mountains near Langmuir Laboratory, New Mexico. The time-of-arrival system consisted of three omni-directional B-dot sensors with a 92 m baseline and two computer controlled time interval counters with ±20 ps resolution.

The Rocket-Triggered Lightning Program: 1983 Results

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Air Force Wright Aeronautical Laboratory
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During the 1983 summer thunderstorm season, the Air Force Rocket Triggered Lightning program was conducted on the east coast of Florida approximately 30 kilometers south of KSC. During this experiment, a total of 18 flashes were triggered using small wire-towing rockets. This paper is a brief description of that experimental setup and an initial analysis of some of the results obtained. The most complete data set was obtained for the flashes triggered on 14 August. On this day, three flashes were triggered using a grounded wire. A fourth was triggered using an ungrounded or "TIPSY" mechanism. During two of the grounded wire triggered flashes, at least a portion of the flash attached to the instrumented Lightning Strike Object (LSO) that was suspended in a wooden scaffold at the triggering site. Data from the LSO sensors, the resistive shunt on the ground below the LSO and the electro-magnetic sensors at the triggering site are correlated with similar data recorded at a measuring site approximately 600 meters from the launch site and with high speed movies of these flashes. This information is used to describe the flashes, the electro-magnetic characteristics of the individual strokes, and the responses of the LSO to these nearby and attached flashes.

The Waveforms of Lightning Radiation Fields

E. Philip Krider[1] and Charles D. Weidman[2]
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ABSTRACT

The electromagnetic fields that are radiated by preliminary breakdown processes, leader steps, and return strokes in cloud-to-ground lightning all have different but characteristic signatures that contain large, submicrosecond field variations. Measurements of lightning E and dE/dt fields have been made in Florida under conditions where the lightning locations were known and where any distortions due to the measuring equipment or to ground-wave propagation were minimal below about 20 MHz. Values of the maximum dE/dt produced by the initial, fast-rising portion of a return stroke range from 7×10^8 V/m/s to 7.6×10^9 V/m/s, when range-normalized to 1 km, with a mean and standard deviation of $3.3 \pm 1.4\times10^9$ V/m/s. If these fields are radiated by an individual current pulse that propagates upward at a speed of 10^8 m/s, then the above values of dE/dt imply that the maximum dI/dt in return strokes ranges from 3.5 to 10^{10} to 3.6×10^{11} A/s, with a mean of $1.5 \pm 0.7\times10^{11}$ A/s, values that are substantially higher than those assumed by most engineering test standards. Leader steps that are close to the ground and the large-amplitude components of intracloud discharges frequently produce dE/dt signatures that are very similar to those from return strokes.

[1] Also, Lightning Location and Protection, Inc., Tucson, Arizona 85719

[2] Present address: Centre National d'Etudes des Telecommunications, LAB/MER-GER, B.P.40, 22301, Lannion, France.

NATURAL FREQUENCIES OF A POST WITH A LIGHTNING RETURN STROKE ATTACHED

F.C. Yang and K.S.H. Lee

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ABSTRACT

The natural frequencies are calculated for a metallic post with a lightning channel attached. Two different lightning channel models are discussed and the asymptotic antenna technique is employed to solve the problem formulated in terms of an integro-differential equation. The results are presented by way of figures and approximate analytic formulas. Applications of the results are also briefly discussed.

MODEL FOR LIGHTNING RETURN STROKE WITH CORONA*

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Louis Baker
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ABSTRACT

An electromagnetic model of a return stroke is developed. The lightning channel is assumed to be surrounded by a corona which stores charge in the form of negative ions. This region then breaks down upon the passage of a potential wave and supplies the charge tapped by the stroke. This region is modeled as a voltage-dependent capacitance in a transmission line model. Analytic solutions are developed for this nonlinear transmission line for zero channel resistivity and infinite conductivity of the corona region. Both continuous and shock solutions are found.

It is shown that in general a dissipationless shock cannot form at the head of the wave, but that some energy must be lost (to channel heating and radiant emission) if it is to match to a continuous solution behind. The electromagnetic emission is largely confined to the area near the wave front, as might be expected.

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*This work was performed under Air Force contract F29601-82-C-0027.

RETURN-STROKE TRANSMISSION-LINE MODEL*

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ABSTRACT

A simple transmission-line model is developed for the lightning return stroke. It is treated as a transmission-line surrounded by a corona discharge [1]. Hydrodynamic channel expansion, radiative losses, channel resistance, non-linear line capacitance are included in the model by means of a "two-zone" model which is an extension of those developed by Strawe [2] and by Braginskii [3]. The resulting equations are solved numerically using the AFWL CRAY-1, typical runs requiring only a few seconds of CPU time. Once channel geometry, etc. are specified there is only one ad hoc parameter, which is equivalent to specifying the wave speed along the transmission line.

The shape of the current pulse is shown to change substantially with propagation; simple models without channel resistance ("ideal transmission lines") can be misleading in this regard, as they predict current pulses that preserve shape as they propagate up the line. The fall-off in the radiation-zone fields is due to the decrease in I-dot at the front, which is caused by an increase in front rise time, before the current amplitude decreases substantially. In contrast, ideal transmission line models give radiation-zone fields of the same shape as the current pulse.

1. C. E. Baum and L. Baker, this conference.

2. D. F. Strawe, "Non-Linear Modeling of Lightning Return Strokes," preprint.

3. S. I. Braginskii, Soviet Physics-JETP, 34, 1068(1958).

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*This work was performed under Air Force contract F29601-82-C-0027.

CALCULATED TEMPERATURE AND BRIGHTNESS OF A LIGHTNING DISCHARGE*

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ABSTRACT

In order to interpret spectroscopic measurements in terms of its internal electrical parameters a detailed model of the energy balance of a lightning discharge has been constructed. We present here a detailed one-dimensional hydrodynamic model of a slice of unit length of a lightning channel as shown in Figure 1.

The energy is input to the channel by joule heating. A known current is impressed on a channel whose resistance is calculated from a conductivity profile which is a function of the local gas temperature. Energy is distributed across the cross section of channel as if it were a set of parallel resistors. The current is assumed to vary slowly enough that the difufsion time is negligible.

Energy losses are more varied. The hot gas loses energy immediately through radiation. In this model radiation losses and redistribution of energy throughout the gas are calculated using multi-group diffusion. Eight frequency bands are chosen and for each a diffusion calculation is performed. The bands are chosen in such a way that the opacity varies by no more than a factor of two over a single band. Hydrodynamic expansions, including pseudo-viscous pressure for shocks is included to complete the energy balance. A complex equation of state for an idealized air molecule is used in the calculations.

This model is intended for use in remote sensing of lightning currents. For that purpose, the model must be experimentally verified. Unfortunately, experiments in which brightness and current are simultaneously measured are not available. However, the model is compared to available experimental data.

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*This work was performed under Air Force contract F29601-82-C-0027.

EXPERIMENTAL DETERMINATION OF OPTIMUM SENSOR LOCATION ON AIRCRAFT FOR TRANSIENT ELECTROMAGNETIC MEASUREMENTS

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To study the characteristics of lightning, aircraft have been instrumented (Baum et al., IEEE Trans. EM Compat., 24, 123-137, 1984) and flown through thunderstorms to measure currents and charges on the aircraft when it is struck by lightning. The NASA F-106 is such an aircraft and has been used for direct strike measurements since 1980. Likewise, the surface currents and charges induced on the aircraft from nearby lightning strikes can also be measured and from these the properties of the lightning strikes are deduced.

One of the main problems when the sensors are mounted on an aircraft is that the sensors respond not only to the incident (i.e., lightning) excitations but to the aircraft responses as well. To obtain a meaningful measurement it is important that a sensor be placed on or near the aircraft so that the field scattered by the aircraft is not received by the sensor.

In this paper the experimental study and some of the results are presented in which the optimum location of a B-dot sensor on a F-106 aircraft to measure the incident magnetic field in the direction of the aircraft fuselage were determined. In the study magnetic field measurements were performed in an anechoic chamber using a 1:72 scale F-106 model illuminated by a plane electromagnetic wave using a small current loop.

Amplitude and phase data were recorded for various locations near the aircraft over 118-4400 MHz (1.6 - 61 MHz full scale). The measurements were made with and without the model and hence a comparison of the two measurements provides a degree of field distortion or error for each location and direction of excitation tested.

PLENARY SESSION C
F. S. K. Center
Chairman: Dr. C. Baum
Air Force Weapons Laboratory
Kirtland AFB, NM

1. 9:00 THE SWISS EMP CONCEPT OF GENERAL DEFENSE, J. Gut, Research Institute for Protective Construction, Zurich, Switzerland

2. 9:30 UNCLASSIFIED UNIVERSITY RESEARCH IN THE EMP FIELD IN FRANCE: AN OVERVIEW, B. Besnault, Laboratoire des Signaux et Systemes, Gif-sur-Yvette, France

3. 10:20 THE APPLICATION OF HIGH LEVEL CURRENT DRIVERS, P. Sevat, Physics Laboratory TNO, The HAGUE, The Netherlands

4. 10:50 A PROGRAM SYSTEM FOR SIMULATION OF THE EMP COUPLING INTO STRAIGHT WIRES AND SPECIAL SURFACES, E. Arnold, AEG-Telefunken, Ulms, and R. Sturm, Federal Armed Forces Defense Science Agency for NBC, Munster, Federal Republic of Germany

5. 11:20 REVIEW OF THE STATE-OF-THE-ART OF NUMERICAL TECHNIQUES FOR ANALYZING ELECTROMAGNETIC COUPLING AND INTERACTION PROBLEMS, A. Taflove, and K. Umashankar, ITT Research Institute, Chicago, IL

THE SWISS EMP CONCEPT OF GENERAL DEFENSE

Jacob Gut
Research Institute for Protective Construction
Auf der Mauer 2, CH-8001 Zürich, Switzerland

The Swiss concept of general defense has been outlined in a report on the security policy of Switzerland in 1973(1). General defense forms the instrument of the security policy by which the strategic goals can be achieved. The development of the international situation and the military threats are analysed in an interim report of 1979(2). Recognizing the enormous damage potential of EMP, a special Board of experts had to study the large scale effects of EMP on a national level. As a result the EMP concept of general defense has been established.

The vulnerability of essential systems to High Altitude EMP (HAEMP) and Low Airburst EMP (LEMP) has been investigated. By governing principles and protection priorities the EMP concept outlines the procedures to reach the goals of EMP protection. These goals are mainly a functioning government, a continued existence of the population and the maintenance of military defense. However, harder conditions and severe limitations in every field have to be accepted in EMP situations.

As a result of the EMP concept of general defense a series of EMP protected systems are required. These include systems of public information, communication, power and food supply, transports etc. At the same time the program of EMP protected constructions and EMP hardened weapon systems has to be carried on(3).

The EMP concept of general defense is illustrated by examples.

(1) Report of the Federal Council to the Federal Assembly on the Security Policy of Switzerland (Concept of General Defense), 27 June 1973

(2) Interim Report of the Federal Council to the Federal Assembly on the Security Policy of Switzerland, 3 December 1979

(3) W. Jöhl, J. Gut, W. Buchmann
A Swiss View of NEMP Protection Principles, EMC Rotterdam 1979 (FMB 79-3)

UNCLASSIFIED UNIVERSITY RESEARCH IN THE EMP FIELD IN FRANCE : AN OVERVIEW

B. BESNAULT

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In France, an important part of the unclassified studies related with EMP is done by university laboratories working in coordination with interested governmental agencies and with some private companies. Some of the results are already published in french journals or conference proceedings, but the purpose of this paper is to give a more extensive view of these works.

Theoretical studies are led on the following items :

- numerical methods in frequency and time domain.
- shieldings, cables.
- antennas responses to an EMP, ground effects.
- EMP simulators.
- lightning effects and analysis.

Related to these theoretical works are experimental ones :

- on site measurements (lighting observations, penetrations through buildings).
- laboratory experiments (comparisons between theoretical and experimental results from simplified models,...).

Future trends of university research in the EMP field will also be outlined.

THE APPLICATION OF HIGH LEVEL CURRENT DRIVERS

P.A.A.Sevat
Physics Laboratory TNO
The Hague, The Netherlands

For testing large and complex electronic systems, like ships, aircraft and communication centers, large and expensive EMP-simulators are needed.
To lower the costs and to avoid damage or disturbance to other equipment in the surroundings of the object under test low level EMP-simulators can be used. An example is the Netherlands transportable EMP-simulator EMIS-3.
The magnitude and shape of the currents at all places of importance in the system are measured. These low-level currents are then extrapolated up to full threat level, taking into account magnitude, shape, cable length, direction of propagation and polarization.

Testing of important and vulnerable equipment in the system can be done afterwards by injecting the extrapolated currents in the cables connected to these equipment by means of high level current drivers. Also the quality of the feed-through in shields, the shielding of the cables, the limiters and the grounding can be tested in this way up to full threat level.
Particularly in cases where the magnitude and shape of the EMP-induced currents on cables can be calculated and no EMP-simulation is needed this injection method is a relatively cheap and efficient way of testing.

Current injection can be distinguished in direct and indirect injection. In this paper the indirect injection by capacitive or inductive coupling is discussed.
Indirect injection has the advantage that the system is tested in the original configuration without disconnecting the cables. An example of inductive coupling is given.

A Program System for Simulation of the EMP Coupling into Straight Wires and Special Surfaces

E. Arnold and R. Sturm
(speaker E. Arnold)

The paper presents the current condition of a programsystem which is under development for computing the coupling of EMP into open or closed metallic bodies. The bodies must be constructed in a simple manner using the following modules: thin straight wires, plane areas with finite dimensions, squares, thick cylinders and cones with circular cross section. The results are the surface currents on the bodies. In addition the physical and the mathematical background is examined, some results are shown as well.

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Dr. R. Sturm, Federal Armed Forces Defence Science Agency for NBC, Protection POB 1320, D-3042 Munster, Federal Republic of Germany

REVIEW OF THE STATE-OF-THE-ART OF NUMERICAL TECHNIQUES FOR ANALYZING ELECTROMAGNETIC COUPLING AND INTERACTION PROBLEMS

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This paper reviews the present numerical techniques available for modeling electromagnetic wave coupling and interaction with three-dimensional structures. Techniques discussed are:

1. Method of moments and the related conjugate gradient technique;
2. High-frequency techniques, particularly the geometric theory of diffraction;
3. Spectral iterative technique and related iterative approaches;
4. Finite-difference time-domain technique;
5. Finite-element technique; and
6. Hybrid methods.

The application of each approach to model three-dimensional structures in the electrical size ranges of 0.1λ and below; 0.1λ - 1.0λ; 1.0λ - 10λ; 10λ - 100λ; and 100λ and beyond, is discussed. In addition, the application of each approach to model structures comprised of conductors, dielectrics, and composite and other anisotropic materials will be reviewed.

This paper will last consider the impact of emerging computer technology upon the available modeling approaches. Factors such as computation speed, storage, and computer architecture will be considered.

SESSION D1
THEORY II
F. S. K. South
Chairman: Dr. W. A. Davis
Blacksburg, VA

1. 1:30 INVITED PAPER: A NOTE ON THE VARIATIONAL METHOD (RAYLEIGH-RITZ), GALERKIN'S METHOD AND THE METHOD OF LEAST SQUARES, T. Sarker, Rochester Institute of Technology, Rochester, NY

2. 2:05 ANTENNA EFFECT ON THE HUMAN BODY TO EMP, K. Grønhaug, Norwegian Defence Research Establishment, Kjeller, Norway

3. 2:30 TIME DOMAIN FINITE ELEMENT METHODS FOR EMP COUPLING, N. Madsen, and J. Peterson, Lawrence Livermore National Laboratories, Livermore, CA

4. 3:15 TIME HARMONIC SOLUTIONS FOR A LONG HORIZONTAL WIRE OVER THE GROUND WITH GRAZING INCIDENCE, K. Chen, Sandia National Laboratories, Albuquerque, NM

5. 3:40 ESTIMATED BULK AND INVIDIUAL CURRENT RESPONSES, T. Liu and F. Tesche, LuTech, Inc., Hayward, CA, and P. Parhami, TRW Inc., Redondo Beach, CA

6. 4:05 USE OF SYMBOLIC MANIPULATIVE CODES IN SOLVING E&M PROBLEMS, M. Tran, and P. Parhami, TRW Inc., Redondo Beach, CA

7. 4:30 RADIATION DAMPING IN FINITE CYLINDERS, I. Gallon, AWRE, Aldermaston, UK

A NOTE ON THE VARIATIONAL METHOD (RAYLEIGH-RITZ)

GALERKIN'S METHOD AND THE METHOD OF LEAST SQUARES

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Variational method (Rayleigh-Ritz), Galerkin's method and the method of least squares have been utilized extensively in electromagnetic theory to solve various field problems. In most cases, one makes a formal use of the techniques. In this paper, a tutorial approach has been taken to bring out the mathematical distinctions between the variational method (Rayleigh-Ritz), Galerkin's method and the method of least squares. Examples have been presented to illustrate the strong and weak points of each of the techniques. Finally, the rates of convergence of the three techniques have been derived.

(Radio Science, Vol. 18, No. 6, pp. 1207-1224, Nov.-Dec., 1983)

ABSTRACT NEM 1984

ANTENNA EFFECT OF THE HUMAN BODY TO EMP

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A preliminary study of EMP induction effects in the human body has been conducted. A cylindrical dipole model of the human body was used to calculate induced currents and energy absorbtion. The cylinder had a length of 1.75 m and a diameter of 25 cm. The cylinder was assumed to have a uniform electrical conductivity.

Frequency domain experiments using a transmission line simulator and a low intensity field were performed in order to verify calculated results. It was found that the human body behaved like a lossy, but efficient dipole. The resonant frequency was in the order of 30 MHz when both feet were in contact with the ground plane.

The total absorbed energy in the body was calculated to be about 10 mJ when a standard exoatmospheric EMP was used as the excitation field. The maximum peak current in the body was approximately 150 A. Since this current was of a very short duration (10 ns) it can not be felt. The results of the study seem to indicate that the probability of harmful effects on humans due to illumination by exoatmospheric EMP is small.

TIME DOMAIN FINITE ELEMENT METHODS FOR EMP COUPLING*

N. K. Madsen

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Livermore, CA 94550

J. C. Peterson

Lawrence Livermore National Laboratory
Livermore, CA 94550

Over the past two years we have explored the use of finite element methods for solving electromagnetic coupling and scattering problems in the time domain. Finite element methods are well known for their ability to readily solve problems where complicated irregular structures or objects are involved.

We have developed a two dimensional time domain code, GEM2D, which implements a Galerkin finite element method for solving Maxwell's curl equations. We will discuss the advantages and disadvantages of our finite element code. We will also show results for several non-trivial EMP coupling problems which will demonstrate the versatility of the finite element techniques.

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

Time Harmonic Solutions for a Long Horizontal Wire Over the Ground with Grazing Incidence

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The grazing incidence of a Nuclear EMP gives the largest induced current on a long horizontal wire over the ground. Previous results in this subject are for the continuous waves (CW) and for an infinite wire extending at both ends. This paper shows the difference in CW responses for a finite horizontal wire and the responses for an infinite wire. First, the transmission line theory due to King et al is extended to higher frequencies. Procedures for obtaining numerical values for the transmission line parameters are given. Second, simple transmission formulas for line currents are applied to obtain the wire current for frequencies ranging from 10 kHz to 1 MHz; ground conductivities of 10^{-1}, 10^{-2}, 10^{-3} S/m; wire heights of 10, 5, and 1m; different load conditions; and different wire lengths. In particular, we report the required wire length so that the long wire will respond as an infinite wire. Thirdly, wire currents for an incident lateral wave are investigated.

ESTIMATED BULK AND INDIVIDUAL CURRENT RESPONSES

Tom K. Liu, Ph.D
Fredrick M. Tesche, Ph.D
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Parviz Parhami, Ph.D
TRW Inc., Redondo Beach, CA 90278

In determining the behavior of a complicated electrical system subjected to an EMP excitation, it is useful to employ various transmission line models for calculating how electromagnetic energy distributes itself within the system. A number of techniques and computer codes have been developed for such analysis. These range from relatively simple, single wire transmission line models, to general transmission line network models.

The use of a general purpose transmission line code, such as QV7TA[1], for studying the behavior of transient voltages and currents on multiconductor lines, yields accurate results. However, it requires large amounts of precise input data to define the multiconductor network, and the computation effort is considerable, requiring to invert large matrices, etc. Often such data may not be available or the computation time is excessive. An alternate method is to first perform the "bulk" or "common" mode analysis of the transmission line network.

The use of bulk mode concept significantly simplifies the analysis procedures. In brief, it reduces the input data requirement of the multiconductor case from matrices and vectors into scalars, and the governing equations for the solution are also scalar. The bulk currents so computed are also readily measurable quantities in reality.

Once the bulk quantities are calculated (or measured), the response of an individual wire inside the multiconductor bundle may be estimated by solving the pair of equations describing the coupling between that wire and the rest of the cable bundle[2]. The methodology of this solution is presented in this paper, together with numerical comparisons with multiconductor analysis.

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[1]F. M. Tesche and T. K. Liu, "User's Manual and Code Description for QV7TA: A general Multiconductor Transmission Line Analysis Code," Interaction Application Memos, August, 1978.

[2]T. K. Liu and F. M. Tesche, "Estimated Bulk and Individual Wire Parameters in the Absence of Detailed Geometry," Report prepared for TRW Inc., under Subcontract No. M00511DR1S, March, 1981.

USE OF SYMBOLIC MANIPULATIVE CODES IN SOLVING E&M PROBLEMS

Minh Tran, Ph.D
Parviz Parhami, Ph.D
TRW Inc., Redondo Beach, CA 90278

The idea of using machines to do analytic calculations was expressed back in 1833 by Babbages' Analytical Engine.[1] With modern computers, this idea is realized by many codes such as SCHOONSCHIP, CLAM, REDUCE-2, SYMBAL, CAMAL, AVTO-ANALITIK, MACSYMA[2], SMP[3]. . . Different codes, however, have been designed for particular fields of interest. For example, SCHOONSCHIP is only used for Dirac's Algebra. For E&M Problems, where wave equations, differential and integral equations, vector and tensor analysis, boundary conditions, etc., are frequently encountered, MACSYMA[2] and SMP[3] are best suited.

The major advantage of using these codes is the simplicity of the programming steps and ease in verifying and testing a given analytical approach. In addition, such codes have already solved problems not possible with the usual programming languages (e.g., FORTRAN). Certain advanced codes (such as SMP) have the ability of producing subroutines for use in the traditional numerical codes.

This paper examines the use of symbolic manipulative codes in solving electromagnetic problems. A sample E&M problem, solved by the SMP code, will be presented and the advantages/shortcomings of such codes will be discussed.

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[1] P. Morrison and E. Morrison (Editors), C. Babbage and his Calculating Engines, Dover, New York, 1961.

[2] R. Bogen et al., MACSYMA Reference Manual, Version g, MIT MathLab Group, 1977.

[3] C. A. Cole et al., SMP, California Institute of Technology, 1981.

SESSION D2
SYSTEM HARDNESS ASSESSMENT
Carrol Room
Chairman: Dr. F. J. Agee
Army Electronics Research and Development Command
Harry Diamond Laboratories, Adelphi, MD

1.
1:30 SERIES EXPANSIONS FOR EVALUATION OF CONFIDENCE IN RELIABILITY OF AN INFINITE POPULATION, W. Herman and J. Williams, Booz, Allen, and Hamilton, Inc., Albuquerque, NM

2.
1:55 EME ASSESSMENT AND HARDENING METHODOLOGIES--EMP VERSUS EW, R. Garver, ERADCOM Harry Diamond Laboratories, Adelphi, MD

3.
2:20 A GENERALIZED NETWORK APPROACH FOR ASSESSING SYSTEM VULNERABILITY AND SURVIVABILITY, G. Corynen, Lawrence Livermore National Laboratories, Livermore, CA

4.
3:15 APPLICATION OF PRA TO EMP FAILURE ANALYSIS, R. Mensing, Lawrence Livermore National Laboratories, Livermore, CA

5.
3:40 A BASIS FOR DEVELOPING EMP HARDENED SYSTEMS, W. Kehrer and J. Castillo, R&D Associates, Albuquerque, NM, and H. Davis, Jaycor, Albuquerque, NM

6.
4:05 MODAL HARDNESS ASSESSMENT, T. Lehman, Science and Engineering Associates, Inc., Albuquerque, NM

7.
4:30 THE CLASSICAL AIRCRAFT EMP ASSESSMENT METHODOLOGY, J. Brossier, TRW, Inc., Redondo Beach, CA, and T. Seale, Defense Nuclear Agency, Washington, DC

Series Expansions For Evaluation Of Confidence In Reliability Of An Infinite Population

William J. Herman and John W. Williams

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Abstract

Bayesian reliability analysis has been a subject of extensive development in the Probability and Statistics Notes. This paper presents a series expansion for confidence in reliability of an infinite population. Comparisons are provided between Bayesian values for confidence (with noninformative prior distribution) and the corresponding values obtained from classical sampling theory. For both cases it is shown that confidence can be conveniently written as a polynomial in R, where R is the lower bound for reliability. Given identical test results and sample sizes, classical sampling theory is shown to generally yield a smaller value for confidence than the Bayesian value obtained with noninformative prior. This difference rapidly decreases as the sample size is increased.

EME ASSESSMENT AND HARDENING METHODOLOGIES--EMP VERSUS EW

by

Robert V. Garver

Electromagnetic pulse (EMP) and electronic warfare (EW) are two aspects of the general problem of electromagnetic effects (EME). In hardening tactical systems the EMP community is concerned primarily with damage from a single nuclear generated transient and secondarily with upset. The EW community is concerned primarily with upset due to modulated rf from a jammer and secondarily with damage. Electromagnetic compatibility (EMC) and Electromagnetic interference (EMI) are like EW, in the effects they can cause, but have different sources in that the EMC energy comes as spillover from our own many radiating sources, while the EMI energy comes from nonintentional radiators and conductors such as commutator transients or switching noise.

The EMP approach to assessment and hardening includes several steps: (1) determining transients onto penetrators, (2) modeling the feed-through of transients to damageable components, (3) determining damage thresholds of components, (4) assessing susceptibility, (5) for susceptible circuits adding protection in the model to the system as required and repeating the assessment, and (6) testing the system to full threat with and without protection to verify the need for and adequacy of hardening.

The EW approach to assessment and hardening of tactical systems involves (1) determining, from system description documents, the internal voltage waveforms that can cause major malfunctions; (2) beginning at the body resonance frequency of the system structure and the modulation frequencies indicated by step 1, testing the structure in a free field environment until upset is obtained at the lowest power density by tweaking rf and modulation frequencies as well as radiation angles and polarization; (3) obtaining upset threshold profiles for a wide range of the above parameters; (4) determining which semiconductor junction is causing periodic bias shift from rectified rf based on the nature of the upset; and, (5) experimenting with changes in the bias circuit, shielding, or grounding to reduce upset sensitivity. When damage is of concern the methodology is extended to include (6) finding the rf detection sensitivity of the upsetting junction by direct injection; (7) calculating the effective capture area of the junction based on the known level of internal waveform and the external power density for upset; (8) determining the damage threshold of the component; (9) assessing the external power density for damage; and (10) repeating and augmenting step 5 as required for sufficient hardening.

The EMP and EW communities have a strong common interest in resolving technology problems such as: characterization of integrated circuits, coupling, measurement techniques, statistical analysis, integrated protection, and methodology standardization.

A Generalized Network Approach for Assessing System Vulnerability and Survivability*

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Abstract

We discuss a framework for evaluating the vulnerability and survivability of systems which operate in stressful environments. Although applicable to a wide variety of complex systems, it is particularly powerful when applied to systems exposed to weapons effects such as EMP, where certain modeling assumptions are naturally satisfied.

Other methods for obtaining vulnerability and survivability exist, but they have various limitations. From a modeling point of view, current methods do not satisfactorily address dynamical issues such as event timing and delays, network problems such as routing of messages, and hierarchical issues associated with command and control structures. From a computational viewpoint, current methods are inefficient, and their complexity increases exponentially as the size of systems is increased linearly.

Our generalized network approach involves a new modeling and computation method. The modeling method consists of a two-tiered hierarchical approach involving a network tier at the top and subsystem tier below. The network tier represents flows of information, controls, and actions, and explicitly accounts for the timing of events and any delays. In this tier, performance is determined by the performances of nodes and links of the network.

The purpose of the subsystem level is to model each node and link of the network as a subsystem of interconnected components in order to allow a thorough description of flows into and out of nodes and of flow transformations within nodes.

Our computation approach is based on the methods of discrete mathematics, which allow a full exploitation of network and tree structure, thereby gaining considerable efficiency. In contrast to current methods, the complexity of our approach is polynomial.

To guide the user in the computer implementation of network models, we have developed the notion of a Cybernetic Module (C-Module), which provides a highly structured interface between the network and the subsystem level.

Our presentation will provide examples of how the framework is used, and will describe typical computations required to assess system vulnerability and survivability.

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

Application of PRA to EMP Failure Analysis*

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Studies of the effects of EMP on large electronic systems such as aircraft or cummunication systems have frequently involved scale model and/or full scale testing. Both approaches have disadvantages. Probabilistic Risk Analysis (PRA) is an alternative approach which uses probabilistic models to simulate the variability of the EMP threat, coupling and component susceptibilities. The probability models together with a systems model provide an analytical method for assessing the failure of electronic systems due to an EMP.

This paper will describe how PRA methods can be used to analyze the vulnerability of electronic systems to EMP. Descriptions of the probability models are necessary inputs into a PRA. Such descriptions are usually based on test data, engineering judgement and/or expert opinions, all of which represent limited information about the real physical phenomena. Thus, such inputs are subject to uncertainties. The PRA method described involves a two-stage estimation process which produces a "best estimate" of the probability of system failure as well as bounds for the probability which describe the uncertainties associated with the inputs.

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

A BASIS FOR DEVELOPING EMP HARDENED SYSTEMS

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R & D Associates
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H. T. Davis
JAYCOR
Albuquerque, New Mexico

Aircraft systems present a unique set of problems in initially verifying EMP hardness and maintaining hardness throughout the system's operational lifetime. Three complicated quantities must be considered during the hardening, verification and life-cycle phases of a system hardness assurance program. To achieve a specific hardening level the following inequality relating these three quantities must be met:

$$\text{system strength} \geq \text{stress} + \text{margin}$$

This paper will concentrate on presenting the parameters that must be considered which will result in forcing the above inequality. In particular, the errors and variations which control the magnitude of the margin required will be discussed. Various approaches which lead to the implementation of the inequality will also be discussed.

MODAL HARDNESS ASSESSMENT*

T. H. LEHMAN
SCIENCE AND ENGINEERING ASSOCIATES, INC.
ALBUQUERQUE, NEW MEXICO

There are many seemingly unresolvable issues associated with the existing methods used for assessing or validating the EMP hardness of complex systems. Most of these issues arise because (1) a unique worst case threat is not definable, (2) it is assumed that component failures are independent, and (3) a super threat level simulation capability is not available. The theoretical framework for all existing methods is constrained by the prevailing philosophy that exact replications of the EMP environment or EMP induced responses are required for assessments to be valid. If this constraint is relaxed or removed, then other assessment methods are applicable and many of the issues can resolved.

In this paper, one such method, modal hardness assessment, is presented. The theoretical framework for this method is based on partitioning the system into its primary energy coupling modes for EMP interactions. With this partitioning scheme, it will be shown that a simple relationship for the system level hardness margin in terms of modal amplitudes can be derived for the case of thermal induced damage. In addition, it will be shown that a unique worst case threat is definable and that super threat level testing can be achieved by stressing each mode separately. Because mode-by-mode component failures are perfectly correlated, it follows that the tails of the threshold distributions can be sampled directly and the data requirements needed to support this method are considerably less than those needed to support standard methods.

*This work was performed under Defense Nuclear Agency Contract DNA001-82-C-0229.

THE CLASSICAL AIRCRAFT EMP ASSESSMENT METHODOLOGY

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Major Tom Seale
Defense Nuclear Agency, Washington, D.C. 20305

This paper presents an overview of the classical aircraft assessment methodology as employed in recent evaluations of several aircraft.

The assessment methodology is based on a stress to strength comparison at the pin level. The strength is analytically determined through circuit modeling and the stress response is obtained through physical testing supplemented with analysis. Improvements have been achieved in both the strength calculation and the stress analysis, and an enhanced understanding of the limitations of the methodology (and prospects for improvement) has evolved. The paper traces the evolution of the assessment protocol and its supporting technologies.

Progress has been steadily made both in the acquisition of the response data and the processing and analysis of that data. Improvements in the instrumentation available on the test site have yielded dramatically increased data acquisition rates while simultaneously improving the quality of data gathered. More comprehensive sampling of the stress response leads to a higher degree of confidence in the final answer through reduction of the associated uncertainties inherent in experimental testing. A modern database management scheme has been implemented to reduce costs and the potential for human error, and to improve access to the data for related technology studies.

SESSION D3
LIGHTNING AND EMP
Hanover Room
Chairman: Dr. J. Corbin
AFSD, Wright Patterson AFB, OH

1.
1:30 INVITED PAPER: COMPARISON OF NEMP-HARDENING AND LIGHTNING PROTECTION REQUIREMENTS FOR MODERN AIRCRAFT EQUIPMENT, D. Jaeger, Messerschmitt-Bolkow-Blohm, Munich, Federal Republic of Germany

2.
2:05 ANALYTICAL COMPARISON OF LIGHTNING AND PUBLISHED CRITERIA ON THE SURFACE OF AN AIRCRAFT, R. Gardner and L. Baker, Mission Research Corp., Albuquerque, NM and C. Baum and P. Andersh, Air Force Weapons Laboratory, Kirtland AFB, NM

3.
2:30 A COMPARISON OF LIGHTNING AND NUCLEAR ELECTROMAGNETIC PULSE RESPONSE OF A HELICOPTER, C. Easterbrook and R. Perala, Electro Magnetic Applications, Inc., Denver, CO

4.
3:40 A COMPARISON OF LIGHTNING AND NUCLEAR ELECTROMAGNETIC PULSE RESPONSE OF TACTICAL SHELTERS, R. Perala, T. Rudolph and P. McKenna, Electro Magnetic Applications, Inc., Denver, CO

5.
4:05 COMPARISON OF LIGHTNING AND THE EMP, J. Nanevicz, J. Hamm and E. Vance, SRI International, Menlo Park, CA

6.
4:05 A BIBLIOGRAPHY OF LITERATURE AND ORGANIZATIONS IN EMP AND LIGHTNING TECHNOLOGIES, A. Mohiuddin, Hughes Helicopter, Culver City, CA

7.
4:30 A PHYSICAL MODEL OF NUCLEAR LIGHTNING, R. Gardner, J. Gilbert, M. Frese and C. Longmire, Mission Research Corp, Albuquerque, NM

Comparison of NEMP-hardening and lightning protection requirements for modern aircraft equipment.

Dipl.-Ing. Dieter Jaeger

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A question often discussed is if NEMP-hardening includes lightning protection of electric/electronic equipment of modern aircraft or opposite if lightning protection will cover the NEMP-threat, too.

This paper tries to give a contribution to this interesting problem by using a very simple aircraft model which is exposed to an external environment.

The model consists of a cylindre with a hole which represents a not electrically sealed access door. A cable runs inside close to the aperture Two kinds of material are considered, aluminum and the modern carbon fiber composite.
The environment is represented by the exoatm. NEMP, the usual standardized lightning pulse and new knowledge about lightning threat.

The results indicate that there is no great difference between lightning and NEMP threat for metallic structures from the point of induced signals but that lightning gets more and more significant for modern carbon fiber aircraft.

Inspite of this fact it cannot generally be stated that lightning protection covers NEMP-hardening because in many cases different classes of equipment may be affected ("safety critical", mission critical").

AN ANALYTICAL COMPARISON OF LIGHTNING AND PUBLISHED CRITERIA ON THE SURFACE OF AN AIRCRAFT*

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ABSTRACT

From the extensive literature on observations of lightning and the public domain criteria for the Nuclear Electromagnetic Pulse (NEMP) (AFWL TR-80-402), electromagnetic environments for these two threats are first established for these two threats to aircraft. For lightning, the waveform for the current in return stroke channel is derived from statistical evidence and from simple physical arguments. For nearby lightning strikes the incident electromagnetic fields are computed from solutions to Maxwell's equations. For the case where lightning directly strikes the aircraft, the problem is complicated by the presence of the lightning channel and the enveloping conrona.

The electromagnetic environment alone caused by lightning and NEMP is not sufficient to compare these two threats since the efficiency with which these threats interact with an aircraft is important as well as the environment. Comparison of relevant currents and charges on the surface of a generic aircraft is presented using a compendium of simple analytical methods applied to simple geometries. Uncertainties in the calculational techniques are also noted.

The conclusion of the paper is that lightning direct strikes dominate NEMP as a threat to an aircraft below about 1 MHz. Above about 10 MHz NEMP is a more severe threat than lightning. Between 1-10 MHz either may dominate, depending on the efficiency of the interaction.

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*This work was performed under Air Force contract F29601-82-C-0027.

A COMPARISON OF LIGHTNING AND NUCLEAR ELECTROMAGNETIC PULSE RESPONSE OF A HELICOPTER

By

C. C. Easterbrook
R. A. Perala

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ABSTRACT

One of the technical areas under current debate in the lightning and NEMP community is the relationship of the lightning to NEMP response of an aircraft. In this paper, we present analytical results which compare both the induced external currents and charges as well as the internal electromagnetic fields and the response of internal cables. The results are favorably compared with those obtained for low level lightning and EMP tests performed on the system.

Our approach is to use the three dimensional time domain finite difference solution of Maxwell's equations. The approach is somewhat novel in that both the exterior and interior are solved simultaneously in a self consistent manner. This is achieved because the helicopter has rather large apertures which can be successfully modeled with cell sizes normally used in the finite difference approach.

The analysis of the aircraft's response shows that the short circuit current on internal cables is larger for lightning, and the open circuit voltage is larger (although not significantly) for NEMP. The lightning response greatly depends upon the rise time of the injected current. Open circuit voltages for a 30 ns rise time approach that of NEMP (20 kV vs 22 kV), but the lightning induced short circuit currents are less (54 A vs 72 A) than that caused by NEMP. On the other hand, for a 2 μsecond rise time source, the lightning induced short circuit current is much larger than that caused by NEMP (441 A vs 72 A) but the lightning induced voltage is much less (4.9 kV vs 22 kV). The energy and power dissipated in a load resistor at the end of the cables is larger for lightning.

The numerical model does give results which are in rather good agreement with those obtained by NEMP and lightning tests. The results also show that internal coupling levels to bulk cables are 20 to 30 dB larger than those observed on fixed wing aircraft. This is principally because of the large number of apertures in a helicopter compared to those in a fixed wing aircraft.

A COMPARISON OF LIGHTNING AND NUCLEAR ELECTROMAGNETIC PULSE RESPONSE OF TACTICAL SHELTERS

By

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P. M. McKenna

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ABSTRACT

One of the technical areas under current debate in the lightning and NEMP communities is the relationship of the lightning and NEMP responses of systems. In this paper, we address the internal response (electromagnetic fields and cable responses) of tactical shelters.

Tactical shelters are usually well shielded systems. Apart from penetrations by signal and power lines, the main leakage paths to the interior are via seams at the edges and the door and the environment control unit (ECU) honeycomb filter.

In this paper, we employ the time domain three dimensional finite difference technique to determine the external and internal coupling to a shelter excited by NEMP and attached lightning. The responses of interest are the internal electromagnetic fields and the voltage, current, and power coupled to internal cables. Leakage through the seams and ECU filter is accomplished by their transfer impedances which relate internal voltages to external current densities. Transfer impedances which have been experimentally measured are used in the analysis. The internal numerical results are compared to actual shelter test data under simulated NEMP illumination.

The results agree quite favorably. They show that the seams are largely resistive, and that the internal response is much larger for lightning than it is for NEMP.

COMPARISON OF LIGHTNING AND THE EMP

J. E. Nanevicz, J. M. Hamm, and E. F. Vance
SRI International
Menlo Park, California

Because most systems that must tolerate the EMP of a high-altitude nuclear explosion are also exposed to natural lightning, it is sometimes postulated that protection against lightning or exposure to lightning can be used to alleviate EMP hardening requirements. The premises are:

- Lightning can deliver more energy than the EMP
- All aircraft and ground-based systems are exposed to lightning.

If it could be concluded from these premises that a system surviving its natural lightning exposure will also be immune to the EMP, great savings in hardening military systems could be realized.

An examination of the electromagnetic characteristics of natural lightning shows that the rare severe cloud-to-ground lightning can deliver transient currents with peak amplitude and action integrals greater than those induced by the high-altitude EMP. The rate of rise of the fields associated with the severe stroke appear to be comparable to that of the EMP, but the amount of data supporting this is small and of recent origin. A few data from aircraft also suggest smaller amplitudes, and somewhat smaller rates of rise are typical of intracloud strokes to aircraft.

However, natural lightning rarely strikes military aircraft or ground-based structures. Historical data on strikes to fighter aircraft suggest that a strike of any kind can be expected only about once every forty years. Strikes to ground-based structures without tall towers occur about once every fifteen years. In addition, lightning stresses only one aircraft or one ground-base facility at a time. In contrast, the EMP stresses an entire fleet of aircraft and a network of ground-based facilities almost simultaneously. Finally, severe lightning, when it strikes, frequently causes catastrophic damage. Hence the assumption that systems tolerate severe natural lightning is not always valid.

It is concluded that the existence of a lightning environment does not eliminate the need for EMP hardening; severe lightning is rarely encountered, but the EMP is almost certain to be encountered in a nuclear engagement.

"A Bibliography of literature and organizations in EMP and Lightning technologies."

by

Ahsan Mohiuddin, Sr. Program Engineer,
SYSCON Corporation, Encino, CA

ABSTRACT

The paper presents an up-to-date bibliography of important literature pertaining to, and various Government, semi-government and industry organizations actively involved in, the disciplines of nuclear EMP and Lightining protection. The literature bibliography is divided into (4) major groups EMP, EMP and other nuclear effects, EMP and Lightning, and Lightning protection. Whenever applicable, security classification and source of procurement have been indicated next to the listed document. The bibliography of organizations is divided into (2) sections, EMP and Lightning: Each section has been divided into (5) major categories, Research, Hardware programs, Systems Engineering and/or technical support of Hardware programs, test facilities and consulting services. A typical organizational listing comprises of address, scope of activity and where possible, a note on past and current programs/ accomplishments. The "Introduction" paragraph discusses chronological development of listed literature with its inter-relationship to major milestones in EMP and Lightning technologies.

Since literature research and contact/rapport with various government, semi-government, industry and non-profit organizations, are considered crucial in establishing and/or maintaining a certain status in any discipline, it is hoped that a bibliography such as this would benefit the members of the EMP and Lightning community in at least two basic ways, (i) by enabling them to establish a sound data base on EMP and Lightning technologies and (ii) by helping them develop contact with different levels of these technologies through inter-communications with other members.

A PHYSICAL MODEL OF NUCLEAR LIGHTNING*

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ABSTRACT

Electrical discharges resembling lightning have been seen on many large-yield surface thermonuclear explosives set off by the United States at Einwetok and Bikini Atolls in the 1950's. The discharges, observed photographically, occur at ranges typically from 900 to 1400 m from the burst and grow upward from the ground or ocean surface at a velocity of approximately 10^5 m/s.

We present here a physical model which describes the processes of the discharge in the nuclear environment. Included are, first, an electrostatic model which forms the foundation for the mechanism for the growth processes and predicts the tip current. Second, there is a detailed model of the process of tip growth within a few centimeters of the tip.

These calculations yield, first a boundary around the lightning channel tip, which defines the region for which the electric field is clamped at the avalanche value, E_a. The field is clamped at this value since exceeding E_a would result in fast formation of electrons, shorting out the field. The field is enhanced to the avalanche value by the conducting core. This boundary is about 1 m in radius at the channel tip. The second calculation is a detailed calculation on a moving grid. The grid velocities are consistent with observations.

*This work was performed under Air Force contracts F29601-81-C-0049 and F29601-79-C-0035.

SESSION E1
THEORY III
F. S. K. SOUTH
Chairman: P. Sevat
Physics Laboratory TNO
The Hague, The Netherlands

1. 8:30 INVITED PAPER: THE ROLE OF COMPUTER MODELS IN EMP APPLICATIONS, E. Miller and G. Burke, Lawrence Livermore National Laboratories, Livermore, CA

2. 9:05 CALCULATION OF SECOND BREAKDOWN WITH SINUSOIDAL WAVEFORMS, A. Ward, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

3. 9:30 AN EVALUATION OF MODELS DIPICTING EMP INDUCED FAILURES IN SEMICONDUCTOR DEVICES, W. Orvis, G. Khanaka and J. Yee, Lawrence Livermore National Laboratories, Livermore, CA

4. 10:15 DESCRIPTION OF THE FIELD ENHANCEMENT NEAR THE EDGE OF A WAVEGUIDE IRIS FOR AIR BREAKDOWN STUDIES, R. Ziolkowski and J. Grant, Lawrence Livermore National Laboratories, Livermore, CA

5. 10:40 CORONA EFFECTS ON EMP INDUCED SURGES IN LONG WIRES, B. McConnell and P. Barnes, Oak Ridge National Laboratory, Oak Ridge, TN

6. 11:05 THEORETICAL AND EXPERIMENTAL ANALYSIS OF HEMP PROPAGATION IN CONDUCTING MEDIA, R. Manriquez and J. Sweton, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

7. 11:30 THE ELECTRON-DEPLETION-LAYER DIODE EFFECT IN IONIZED-AIR-CONDUCTIVITY CIRCUIT LOADING, M. Bushell, J. Deppe, C. Kenyon, G. Merkel, and J. Miletta, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

THE ROLE OF COMPUTER MODELS IN EMP APPLICATIONS*

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Abstract

It has been long felt that computer models must have some role to play in solving EMP coupling problems. Just what that role might be however, seems still to be a subject of some debate and speculation. Certain aspects of the overall problems are reasonably well suited to computer modeling, for example external coupling using integral-equation techniques. Other parts of the problem, internal coupling for example, are apparently more challenging, as they continue to resist a generally workable solution.

The usual approach taken in this kind of situation is to attempt extending the scope of available tools, possibly beyond their regime of practicality. This approach can exhibit only mixed success, as observed above, and may result in concentrating attention on the wrong issues. An alternative approach might be to ask what could be done were an exact, affordable solution or its successive approximations available. Then, having gained some insight about what would be the characteristics of acceptable solutions, effort could be directed to their development with confidence that the right tools are being worked on. In this paper, we discuss aspects of both approaches.

First, we connsider what might he done with an ideal solution that is as detailed, accurate and efficient as desired. We conclude that if such a solution were available, its most logical application would be to developing distributions of responses at selected points within a system. Then, we review current modeling state-of-the-art with respect to the ideal, to see how realizable that ideal might be, and indeed whether its really needed. Finally, we suggest the need for an intermediate approach that explicitely takes into account the uncertainty of the problem specification and solution variability, and combines aspects of both approaches.

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

CALCULATIONS OF SECOND BREAKDOWN WITH SINUSOIDAL WAVEFORMS

A. L. Ward

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Although the EMP pulse is generally a damped sinusoid, most studies of second breakdown have involved a single applied square pulse. This selection is largely due to its simplicity for both the experimentalist and the theorist. The HDL diode computer program[1] has now been used to study current-voltage characteristics of silicon diodes subject to a sinusoidal waveform. Forward and reverse biases must be studied separately. The stored charges from the forward half cycle may be used as initial conditions for the reverse half cycle. Diodes studied range from 0.2- to 100-μm width and are predominantly p-i-n diodes.

At low frequencies, both forward and reverse characteristics differ little from those deducible from constant voltage studies. However, when the carrier transit time becomes an appreciable portion of the half period of the applied waveform, strong frequency effects are calculated. A linear dropoff in peak current with frequency is calculated for the forward-bias half cycle. Above reverse avalanche breakdown, a maximum in the peak reverse current is noted. One observes a sharp, high-frequency cutoff in peak reverse current that is dependent on diode width and overvoltage. At lower frequencies an increase in peak current with frequency is due to the increase in the rate of rise of the applied voltage.[2]

The presence of stored charges from forward conduction reduces the peak current in the reverse cycle under avalanche conditions. The frequency of the high frequency cutoff is reduced at higher temperatures, because of the decrease in mobility. At lower frequencies the magnitude of the forward current peaks increase with temperature, but the reverse current peaks may increase or decrease depending upon device and circuit parameters.

Second breakdown is expected to show a frequency dependence and an initial polarity dependence for decaying sinusoidal EMP pulses.

---

1. A. L. Ward, "Calculations of Second Breakdown in Silicon," Harry Diamond Laboratories, HDL-TR-1978, August 1982.

2. A. L. Ward, "Modes of Avalanche Oscillations in Silicon Diodes," IEEE Trans. Electron Devices, vol. ED-25, pp. 683-687, June 1978.

An Evaluation of the Models Depicting EMP Induced Failures in Semiconductor Devices*

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We have investigated a number of the models available for modeling second breakdown and failure in semiconductor devices. We find that there are basically two types of models, simple analytic models and more complex numerical models. The analytic models are all generalizations of the Wunch-Bell model and, as such, involve only thermal effects. The numerical models range in complexity from simple heat flow calculations to multi-dimensional heat and charge carrier flow models. Both of these approaches have their own merits, problems and sources of error. We have evaluated these models, listing their relative merits and problems, enumerated their sources of error and compared them to measured error distribution and data.

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

DESCRIPTION OF THE FIELD ENHANCEMENT NEAR THE EDGE OF A WAVEGUIDE IRIS FOR AIR BREAKDOWN STUDIES*

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An important issue to an EMP coupling problem is the correct description of the field behavior near any edge such as the rim of an aperture or the lip of an interior partition. This is especially pertinent to questions of air breakdown near edges where the locally enhanced field amplitudes may surpass the air breakdown threshold. A time evolution description of this enhancement phenomena would allow characterization of the breakdown threshold as a function of the features of an input pulse.

Time domain solutions of the capacitive and inductive iris problems in a rectangular waveguide have been obtained and will be described briefly. They are based upon the generalized N-series approach to aperture coupling developed in (1) and (2). Currents on the iris and the field structure near the edge of the iris as functions of pulse shape, iris size, and time will be presented. Preliminary remarks relating these results to the air breakdown threshold question and the corresponding LLNL experimental results will be made.

(1) R. W. Ziolkowski, "N-Series Problems and the Coupling of Electromagnetic Waves to Apertures: A Riemann-Hilbert Approach", UCRL-88906, Lawrence Livermore National Laboratory, Livermore, CA, 1983 (to appear in SIAM J. Math. Anal.).

(2) R. W. Ziolkowski, W. A. Johnson and K. F. Casey, "Applications of Riemann-Hilbert Problem Techniques to Electromagnetic Coupling Through Apertures", UCRL-88169, Lawrence Livermore National Laboratory, Livermore, CA, 1983 (to appear in Radio Science).

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

CORONA EFFECTS ON EMP INDUCED SURGES IN LONG WIRES*

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ABSTRACT

The interaction of high-altitude EMP with a long line results in a fast rising surge with a peak value similar to that of "average" lightning. The rise-time and the peak amplitide are important considerations for coupling and protection analysis. The possibility that corona may alter the rise-time and peak amplitide during the early time regime (the first 100ns) is considered in this paper. An upper bound for the effects of corona is obtained for early-time by using a simple avalanche model. Attachment, recombination, and space charge are approximated to indicate the effects of incorporating these additional complications. This corona model is corrent initially but progressively over-estimates corona effects as time increases. Upper and lower bounds for EMP induced surges which were calculated using this model are presented.

*Research sponsored by the Division of Electric Energy Systems, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

THEORETICAL AND EXPERIMENTAL ANALYSIS OF HEMP PROPAGATION IN CONDUCTING MEDIA

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This paper uses experimental data obtained on a buried, conducting, parallel-plate sensor to evaluate the electric field beneath the earth-air interface. The sensor is described with a simple equivalent circuit and the characteristic response is evaluated both in time and frequency. The agreement between the calculated and measured transmitted electric field is quite good for reasonable values of constant and frequency-dependent electrical conductivity and dielectric permittivity of the earth. The electrical properties of the earth were the only parameters that needed to be adjusted to provide agreement between theory and experiment. Those values taken were considered within reasonable bounds.

The Electron-Depletion-Layer Diode Effect in Ionized-Air-Conductivity Circuit Loading

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The interaction of an Army electronic system with the source region electromagnetic pulse (SREMP) produced by a tactical nuclear weapon is complicated by the presence of time-varying air conductivity. Gamma rays not only ionize the surrounding air, but penetrate into the circuit boxes and ionize the air that surrounds individual circuit components. Ionized air is a relatively good conductor, and can therefore affect the overall interaction of a system to a tactical source region (TSR) EMP. This paper discusses an added complexity that arises at the boundary between ionized air and metallic conductors. Conduction electrons have no difficulty in passing from ionized air into a positively charged metallic conductor, but the opposite is not the case. For a negatively charged metallic surface, the metallic work function (approximately 4 ev) is appreciably greater than the kinetic energy of the metallic conduction electrons (approximately 1/40 ev) and therefore presents a formidable barrier to the passage of electrons from the metal to the ionized gas. In fact, an electron depletion layer can form between the metal surface and the ionized gas. This depletion layer is quite similar to the solid state reversed-bias/diode depletion layer and can be described with analogous physical models.

In the past,[1] depletion layers have been studied in simplified planar geometries. This paper discusses experimental results obtained in concentric experimental geometries and develops a tractable diode model which can be incorporated into circuit codes to study the response of Army systems to the TSR.

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[1] W. F. Crevier, C. L. Longmire, G. Merkel, and D. J. Spohn, Air Chemistry and Boundary Layer Studies with AURORA, IEEE Trans. Nucl. Sci., NS-24, No. 6 (December 1977).

SESSION E2
AIRCRAFT
Carrol Room
Chairman: G. Morgan
Rockwell International
Anaheim, CA

1. 8:30 INVITED PAPER: INTEGRATED EM HAZARDS PROTECTION OF USAF AIRCRAFT, J. Corbin, Air Force Aeronautical System Division, Wright Patterson AFB, OH

2. 9:05 EMP INTERACTION WITH AIRCRAFT/STORE COMBINATIONS, J. Thomson, Royal Aircraft Establishment, Farnborough, and P. Johns, Kimberley Communications Consultants, Nottingham, UK

3. 9:30 EMP HARDENING OF AIRCRAFT WEAPON CONTROL SYSTEMS, R. Rode and D. Jaeger, Messerschmitt-Bolkow-Blohm, Munich, Federal Republic of Germany

4. 10:15 AIRBORNE PLATFORM FOR MEASUREMENT OF TRANSIENT OR BROADBAND CW ELECTROMAGNETIC FIELDS, D. Giri, LuTech, Inc., Hayward, CA, and C. Baum, Air Force Weapons Laboratory, Kirtland AFB, NM

5. 10:40 SHIELDING OPTIMIZATION FOR AIRCRAFT, W. McCloud, Douglas Aircraft Company, Long Beach, CA, and J. Chai, TRW Inc., Redondo Beach, CA

6. 10:05 DETERMINING AIRCRAFT VULNERABILITY TO MICROWAVE THREATS USING COUPLING PATH TRANSFER FUNCTION MEASUREMENTS, D. Auckland, Syracuse Research Corporation, Syracuse, NY, and J. Birken, Naval Air Systems Command, Washington, DC, and R. Anderson, and L. Ruhnke, Naval Research Laboratory, Washington, DC,

7. 11:30 LOW-LEVEL VERSUS NEAR THREAT EMP EXCITATION OF AIRCRAFT, C. Padget, and P. Parhami, TRW Inc., Redondo Beach, CA

INTEGRATED EM HAZARDS PROTECTION OF USAF AIRCRAFT

John C. Corbin
Air Force Aeronautical Systems Division
Directorate of Avionics Engineering
Wright-Patterson AFB, Ohio 45433

ABSTRACT

The paper describes present electromagnetic interference (EMI), electromagnetic pulse (EMP) and lightning protection requirements for USAF aircraft and discusses efforts underway to integrate these requirements.

EMP INTERACTION WITH AIRCRAFT/STORE COMBINATIONS

Dr J M Thomson
Flight Systems Department
Royal Aircraft Establishment
Farnborough, Hants, UK

Professor P B Johns
Kimberley Communications Consultants
Minerva House, Spaniel Row
Nottingham, UK

The increasing adoption of electronic stores management systems has highlighted the need to understand the interaction of EMP with aircraft/external weapon store combinations. Such stores may be hung either from the centre fuselage or from wing pylon stations. EMP can couple to exposed cables which may be in umbilicals connecting the aircraft and store or, particularly in the case of missiles, in external raceways. Such interactions do not appear to have been treated in depth in the literature, the closest approach being various analyses of pickup on external missile raceways.

As a first approximation it can be postulated that when the store is attached to the centre fuselage it is essentially part of the aircraft, with its response dominated by the aircraft response; and that when hung from a wing it essentially behaves as a missile in free space.

We have investigated the case of the store in the centre fuselage position. We have done this both theoretically, using the transmission-line model of electromagnetic wave propagation [1], and experimentally, using a simplified scale model. In both cases the representation has been two cylinders whose lengths (and also diameters) are in the ratio 4:1 and which are interconnected by three crutches of variable length (see Fig 1). These crutches represent the forward and rear struts of the store pylon and the centre umbilical. For the experimental work the larger cylinder had a length of 2m and a diameter of 0.5m.

Preliminary observations of the surface currents on the aircraft and store have now been made and indicate that crutch length and, particularly, diameter are less important than the direction of the incident wave.

[1] S Akhtarzad and P B Johns: "Solution of Maxwell's equations in three space dimensions and time by the tlm method of numerical analysis"; Proc IEE (UK), Vol 122, No 12, pp 1344-1348, Dec 1975

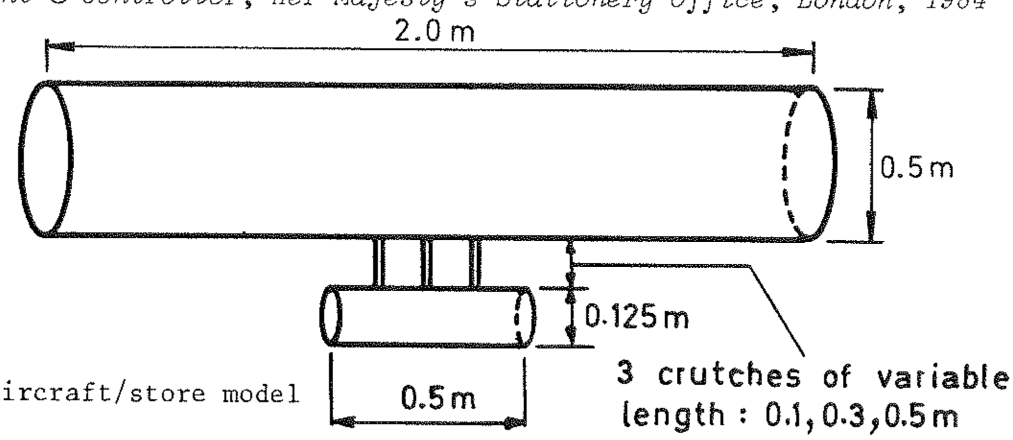

Fig 1 Aircraft/store model

EMP Hardening of Aircraft Weapon Control Systems

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Modern aircraft contain an increasing number of sophisticated electronic systems consisting of new elements like Integrated Circuits, VLSI components or EEPROMs operating with high data exchange rates on special data buses (eg MIL-Bus 1553 B). All these elements can be especially sensitive against an EMP and it should be ensured that the overall weapon system is still fully operable after an EMP has occured and that a mission success is still possible.
The lecture describes the principles of current and future weapon control systems with special emphasis on those parts which may be sensitive to EMP influence.
Considerations comparing the exo- and endoathmospheric NEMP together with polarisation considerations result in the view that the exoathmospheric NEMP covers all other NEMP aspects in respect of weapon control systems application.

Resulting from above it can be calculated which limits (directly injected through cables or via radiated fields) installed equipment has to withstand without destruction.

The following system elements are considered in this context:

a) Interface equipment/aircraft (eg cables, MIL-Bus)
b) Installed equipment
c) Interface equipment/weapons (eg ERUs)
d) Weapons

The situation and enhancement proposals for all these elements are discussed.

To finally ensure that the overall weapon system is safe under EMP conditions and operable afterwards, the full aircraft should be tested in an appropriate EMP simulator. The calculated test limits should prove the acceptable design including a safety margin.

AIRBORNE PLATFORM FOR MEASUREMENT OF TRANSIENT OR BROADBAND CW ELECTROMAGNETIC FIELDS

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Abstract

This paper deals with the development of considerations and guidelines useful in designing an airborne platform for the measurement of transient or broadband CW electromagnetic (em) fields. The em problem consists of choosing the appropriate sensor type and location such that the scattered fields from the aircraft and sensor mounting do not significantly couple to the sensor, while measuring the incident field.

Symmetry [1] and topology considerations are applied in choosing the type of sensor, its connection to the aircraft, and the type of measurement. This leads to the antisymmetric measurement (no net current along fuselage) of the incident magnetic field along the fuselage axis. For this particular measurement, methods of minimizing: (a) antisymmetric coupling from wings and horizontal stabilizers, (b) quasimagnetostatic antisymmetric fields scattered by the fuselage and (c) high frequency antisymmetric errors will be discussed. It is also noted that the consideration of forward or aft sensor locations is aircraft specific. For example, location of wings and/or horizontal stabilizers, delta vs. conventional wings, jet engine exhausts if on or near symmetry plane are all factors influencing the sensor location. An example design [2] of magnetic field sensor on F-106 aircraft will be presented along with available scale model measurements for this aircraft for varying sensor locations.

References

[1] C.E. Baum, "Interaction of Electromagnetic Fields with an Object which has an Electromagnetic Symmetry Plane," Interaction Note 63, 3 March 1971.

[2] D.V. Giri and S.H. Sands, "Design of $\dot{B}$ Sensor for the Nose Boom of F-106B Aircraft," EM Platform Memo 1, 5 Sept. 1983.

Both of the above references can be obtained from the authors, or the Defense Documentation Center, Cameron Station, Alexandria, VA 22314

Shielding Optimization for Aircraft

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To protect the vital electronic devices on the aircraft from EMP-induced transients, braided-wire cables and metal enclosures are often used in the major ports of entry (POE) areas. For more effective braided-wire shielding, smaller transfer impedance $Z_T(\omega)$ and transfer admittance $Y_T(\omega)$ are required [1].

The effort to minimize the transfer impedance $Z_T(\omega)$ is based on the following considerations: for frequencies well below 1Mhz, the dominant diffusion term is fairly insensitive to frequency variations; for frequencies about 1 Mhz, the penetration term becomes increasingly important. In the optimization procedure, this penetration term is minimized for a given cable radius by selecting appropriate shield parameters which would provide an optimum optical coverage for the braided-wire shield. The cable response at high frequencies corresponds to that at early time where the peak response of a cable is likely to occur. Therefore, optimizing the shielding at high frequencies is effective in reducing the peak response of the cable. Since the transfer admittance $Y_T(\omega)$ has a similar $(1-k)^{3/2}$ behavior (where K is the optical coverage) as $Z_T(\omega)$, the optimization procedure described above is also valid for $Y_T(\omega)$.

A three-dimensional plot gives an example of the correlation among the shielding parameters of a braided-wire shield for optimal shielding. The significant improvement in the shielding effectiveness using the optimized shielding parameters over a typical un-optimized braided-wire cable can be seen from the second graph.

[1] Vance, E. F., "Coupling to Shielded Cable", John Wiley and Sons, Inc., 1978.

DETERMINING AIRCRAFT VULNERABILITY TO MICROWAVE THREATS USING COUPLING PATH TRANSFER FUNCTION MEASUREMENTS

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R. Anderson
L. Ruhnke
Naval Research Laboratory
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Electromagnetic environments created by microwave emitters having very large power-aperture products pose a potentially hazardous threat to modern military aircraft which incorporate sophisticated avionics packages. The Naval Air Systems Command has maintained extensive test programs to qualitatively assess the vulnerability of Navy fleet aircraft to shipborne electromagnetic environments (i.e., ASEMICAP or Air Systems Electromagnetic Interference Corrective Action Program). An effort is currently being directed toward embellishing this qualitative data obtained for simulated shipborne environments with quantitative microwave vulnerability data. A first step toward achieving this goal can be taken by measuring the coupling path loss between a likely point-of-entry and an avionics bay area. This may be done at low levels using a swept CW transmitter connected to a horn antenna outside the aircraft and a spectrum analyzer connected to a receiving horn inside the closed avionics bay. Knowledge of the electromagnetic environment coupled into the avionics bay, as well as the electromagnetic environment levels to which sensitive equipment has been military-qualified (i.e., MIL-STD-461) allows calculation of a margin of protection that the equipment exhibits against upset or burnout due to expected high power microwave threats. This paper illustrates the application of this methodology to a current fleet aircraft and summarizes the methodology of the Navy's IMMASH (Intense Millimeter and Microwave Aircraft System Hardening) test program.

LOW-LEVEL VERSUS NEAR THREAT EMP EXCITATION OF AIRCRAFT

Carl Padgett
Parviz Parhami, Ph.D
TRW Inc., Redondo Beach, CA 90278

Linearity is a key assumption when extrapolating EMP test results to a criterion threat. This assumption forces most EMP system tests to be performed at near threat simulators. Indeed, system upset evaluation is a highly non-linear science and can only be tested in threat (or near threat) environments.

The permanent damage evaluation, however, compares the electrical strength of a circuit with that of the electrical stress induced by the Criterion EMP threat. A low-level coupling test (having an adequate bandwidth) is an alternate way of predicting these electrical stresses. To increase the confidence in such a procedure, and to discount any non-linear properties which may invalidate the procedure, an extensive experimental data base is needed.

In recent EMP test at HPD/VPD simulator facilities at Kirtland AFB, an experiment was conducted to contribute to such a data base. The test aircraft was positioned and tested at predetermined distances from the two simulators. The result was an extensive set of internal measurements in environments ranging from 5 to 55 KV/m. This paper will summarize and present the findings of this experiment.

SESSION E3
SREMP AND SGEMP
Hanover Room
Chairman: D. Merewether
Electro Magnetic Applications, Inc.
Albuquerque, NM

1. 8:30 INVITED PAPER: SOURCE REGION EMP COUPLING, D. Merewether, Electro Magnetic Applications, Inc., Albuquerque, NM

2. 9:05 STATIC SPACE CHARGE MODEL FOR EXTERNAL SGEMP, M. Schmidt, Science Applications, Inc., McLean, VA

3. 9:30 USE OF SHRUNKEN ANALOG SYSTEMS TO SIMULATE THE RESPONSE OF EXTENDED SYSTEMS TO A SREMP ENVIRONMENT, M. Bushell, R. Manriquez, G. Merkel, J. Miletta and W. Scharf, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

4. 10:15 ENHANCED-RISE-TIME BREMSSTRAHLUNG AURORA ENVIRONMENT, M. Bushell, S. Graybill, M. Litz, G. Merkel, and D. Troxel, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

5. 10:40 MEASUREMENT AND ANALYSIS OF THE ELECTROMAGNETIC ENVIRONMENT PRODUCED BY DIRECT INJECTION OF RELATIVISTIC ELECTRONS, M. Bushell, J. Deppe, K. Kerris, G. Merkel and D. Whittaker, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

SOURCE REGION EMP COUPLING

by

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ABSTRACT

Close to a nuclear burst the EMP response of wire antenna and metal strucutres is altered by the presence of air conductivity caused by ionizing radiation. This increases the low-frequency content of EMP induced voltage and currents on antenna terminals, power lines, and communication cables, and may enhance the deleterious effects of EMP on electronic systems connected to these conductors.

The ionizing radiation also engenders Compton currents that induce EM fields inside enclosures, equipment compartments and even electronic boxes. Additionally, these currents directly impress currents and voltage on wires inside shielded cables and on the foil traces of printed circuit cards. These interior sources of EMP excitation can circumvent protective measures installed to harden systems to survive high-altitude burst EMP (HABEMP) environments.

In this paper, the flowdown of source region EMP into a typical ground system is discussed. Simple coupling models and parametrically determined results are used to describe the coupling phenomena and to establish the significance of the exterior and interior facets of the source region EMP (SREMP) environment.

The procedures to be used to harden systems to survive an SREMP environment are described, and the way these procedures differ from the procedures appropriate for HABEMP environments are discussed.

STATIC SPACE CHARGE MODEL FOR EXTERNAL SGEMP*

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An analytic static model is developed to reproduce the highly non-linear space charge scaling laws for external SGEMP. This static model gives enough physical insight into external SGEMP phenomena that it is an attractive candidate to calculate SGEMP system stresses as opposed to more expensive techniques of self-consistent particle pushing and P-dot driver numerical codes.

In this paper, we describe the Static Space Charge External SGEMP Model by comparing it to numerical results produced using large time consuming electromagnetic particle pushing computer codes.[1] The comparison demonstrates that the static SGEMP model does indeed take into account all the important physics of this phenomena that would be relevant to system hardening design.

The static SGEMP model is nothing more than estimating the final charging voltage of an isolated body with respect to infinity by calculating the number of photoelectrons that had enough energy to escape the electrostatic potential of the body. This concept expressed mathematically is:

$$CV = Qe^{-V/\bar{V}}$$

where V is the isolated body voltage, C is the body capacitance, Q is the total number of photoelectrons, and $\bar{V}$ is the average temperature of the photoelectron population. This equation can be solved for body voltage and used to estimate SGEMP generated body current.

Parameter regimes for the validity of this model is explored and arguments presented why the static solution dominates over the radiative effects present in the real problem.

REFERENCES:

1. Woods, A. J. and E. P. Wenaas, "Scaling Laws for SGEMP", IEEE Trans. Nuc. Sci., NS-23, No. 6, December 1976.

*This work was supported by the DEFENSE NUCLEAR AGENCY under Contract Number DNA001-81-C-0005.

Use of Shrunken Analog Systems to Simulate the Response of Extended Systems to a SREMP Environment

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Military systems frequently extend over ground areas and volumes that are much greater than the areas and volumes illuminated by existing EMP or SREMP simulators. This is especially true in the cases in which ionizing radiation plays an important role. For example, the Aurora test cell floor is only 12 by 25 m in area. If a system involves long antennas or long cables, it is usually impossible to illuminate the entire system. It is therefore necessary to replace an extended part of the system, such as a long cable or a long antenna, by a current injection module.

The scheme to be discussed is an extension and continuation of work reported on in the 1982 NEM conference.[1] The extended system is replaced by a physically shrunken analog system that obeys the same differential equations as the system to be mimicked and by a current injector. For example, a long cable can be replaced by a slow-wave structure that is described as far as possible by the same set of coupled differential equations as the extended system. This, of course, is not always possible, and compromises must be made. Although this approach may appear quite involved, it is frequently very simple, and the behavior of an extended system can be mimicked with a great deal of verisimilitude. The weaknesses and strengths of the approach will be presented in terms of a 45-m-long horizontal antenna whose SREMP response is mimicked by a helical slow-wave structure.

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[1] C. Berkeley, M. Bushell, C. Kenyon, R. Manriquez, G. Merkel, and W.D. Scharf, "Simulation of the Response of Long Cables in the Aurora Test Cell with Slow Wave Structures," 1982 NEM Meeting, Albuquerque, New Mexico, May 24-28, Abstracts of Technical Papers, p. 117.

ENHANCED-RISE-TIME BREMSSTRAHLUNG AURORA ENVIRONMENT

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The rise time of the Aurora bremsstrahlung pulse when Aurora is operated in its conventional four individual thick target mode is relatively slow. The individual thick target bremsstrahlung sources each have rise times of about 40 or 50 ns. Because of jitter, the rise time of the total bremsstrahlung pulse produced by the four bremsstrahlung targets is about 50 to 70 ns.

Recently, the technique of beam nose erosion, developed by Miller[1] of Sandia National Laboratories, has been employed at one of the diodes of Aurora to obtain a faster rise-time pulse. In the new beam-front erosion mode, the bremsstrahlung rise time can be as low as 15 to 20 ns. In this technique the relativistic electron beam from one Aurora diode is passed through a 2-m-long low-pressure pipe before the beam impinges on a thick bremsstrahlung target. The early part of the beam cannot propagate along the rise-time-sharpening pipe section until the proper balance of charge distribution and return current necessary for stable beam propagation has been achieved. The air in the beam-sharpening section has to be ionized to allow stable beam propagation. The ionizing radiation environment produced in the Aurora test cell and the electromagnetic environment produced in the Aurora test cell were measured at a number of positions. The dose in the Aurora test cell is appreciably less than when Aurora is operated in the conventional bremsstrahlung mode. The results of these electromagnetic measurements have been interpreted with a finite-difference code. The calculated and experimental results will be compared.

1 R. B. Miller, An Introduction to the Physics of Intense Charged Particle Beams, Ch. 5, New York, Plenum Press (1982).

Measurement and Analysis of the Electromagnetic Environment Produced by Direct Injection of Relativistic Electrons

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The electromagnetic environment produced outside the Hermes Facility building at Sandia National Laboratories by direct injection of 8-MeV relativistic electrons into the open air has been measured with electric field and magnetic field sensors. The total dose distribution of ionizing radiation was determined with thermoluminescent dosimeter techniques. The dose rate distribution was determined at a number of positions with scintillation counters. The spatial and time distribution of relativistic electron current was then estimated from the spatial total dose distributions and dose rate measurements. The estimated relativistic electron current density distribution was then employed as the current driver in a three-dimensional, finite-difference-code Maxwell equation solver to calculate the electric field and magnetic fields in the region surrounding the Hermes electron beam.

The experimental electric and magnetic field measurements have been compared to the calculated results. The comparisons will be discussed along with possible explanations for divergence between calculated and experimental results when these divergences do occur.

SESSION F1
CABLES AND TRANSMISSION LINES

F. S. K. South

Chairman: Dr. J. Haseborg

Technical University, Hamburg-Harburg, Federal Republic of Germany

1. 1:30 USE OF GENERAL MULTICONDUCTOR TRANSMISSION LINE ANALYSIS CODE FOR THE STUDY OF EMP EFFECTS IN HV NETWORKS, M. Ianovici, Swiss Federal Institute of Technology, Lausanne, Switzerland, and F. Tesche, LuTech, Inc., Hayward, CA

2. 1:55 THE HEMP RESPONSE OF A LONG TRANSMISSION LINE BURIED IN THE EARTH, R. Manriquez, R. Reyzer, and J. Sweton, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

3. 2:20 COMPARISON OF METHODS FOR MEASURING THE CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINES, L. Hoeft and J. Hofstra, The BDM Corporation, Albuquerque, NM

4. 3:15 ANALYSIS OF THE EFFECTS OF CABLE PARAMETERS ON FIGURES OF MERIT SUCH AS "EMP RESPONSE", L. Hoeft, A. Lindner and J. Hofstra, The BDM Corporation, Albuquerque, NM

5. 3:40 MEASURED TRANSFER IMPEDANCE OF METALLIC AND NON-METALLIC CONDUITS COVERED WITH TINNED COPPER AND SnCuFe BRAIDS, J. Merrill, Glenair, Inc., Glendale, CA, and L. Hoeft and J. Hofstra, The BDM Corporation, Albuquerque, NM

6. 4:05 INTERACTION OF HIGH-ALTITUDE ELECTROMAGNETIC PULSE (HEMP) WITH TRANSMISSION AND DISTRIBUTION LINES: AN EARLY TIME CONSIDERATION, K. Lee, F. Yang and N. Engheta, Dikewood, Santa Monica, CA

7. 4:30 SIMPLIFIED METHOD OF SOLVING TRANSMISSION LINE NETWORK PROBLEMS, T. Liu, LuTech, Hayward, CA, and P. Parhami and J. Chai, TRW Inc., Redondo Beach, CA

USE OF A GENERAL MULTICONDUCTOR TRANSMISSION LINE ANALYSIS CODE FOR THE STUDY OF EMP EFFECTS IN HV NETWORKS

by M. Ianovici-Swiss Federal Institute of Technology, 16 ch. de Belle rive 1007 Lausanne, Switzerland

and F. M. Tesche-LuTech,Inc. 3516 Breakwater Court, Hayward,Ca94545,USA

A multiconductor line analysis code developed previously has been successfuly used for the study of the transient behaviour of transmission lines subject to either lumped source or distributed field excitation. |1|. This code considers the resistance of the conductors negligible and takes into account only the series inductance and the parallel capacitance.

The aim of the present work was to use the program for the study of EMP effects on HV networks. For this an important improvement of the code has been achieved by taking into account the conductors resistance and therefore the attenuation due to losses in the network.In this case the complete complex expressions in matrix form of the propagation constant and of the characteristic impedance must be introduced in the program.

The validity of this approach has been verified for a single aerial line and for a complex HV network consisting of 9 interconnected three-phase lines of different lengths and positions in the space.

The values of induced currents and voltages obtained when the losses are taken into account are considerable smaller compared to the case of the network with zero resistance.For instance, for the interconnected network values of 100-200 kV for the voltage and less than 1 kA for the current have been calculated. These values are of the same order of magnitude as those reported by other authors|2|.

It can be concluded that the currents induced by an EMP in a HV network should not exceed currents usually measured in the case of lightning strokes or short-circuits with the difference however that it acts simultaneously on an entire network.

References

|1|F. M. Tesche et all.,Field excitation of Multiconductor Transmission Lines,EMP Interaction Notes EMP 3-39,July 1979.

|2|J. H. Marable et all. Power System EMP Protection, ORNL-4958,UC-35, May 1975.

THE HEMP RESPONSE OF A LONG TRANSMISSION LINE BURIED IN THE EARTH

R. P. Manriquez, R. J. Reyzer, and J. F. Sweton

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The current induced by an electromagnetic pulse (EMP) on a long, terminated insulated cable buried at shallow depth near the earth-air interface, has been measured and compared with analytical predictions. The main objectives of this paper are to evaluate the plane-wave electromagnetic field propagation through a linear, isotropic, and homogeneous conducting media; to represent the EMP coupling to the buried cable by the distributed-source, lumped-parameter equivalent network model; and to compare these data to experimentally collected data.

COMPARISON OF METHODS FOR MEASURING THE CHARACTERISTIC IMPEDANCE OF TRANSMISSION LINES

L. O. Hoeft and J. Hofstra
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A knowledge of the characteristic impedance of transmission lines is a fundamental input to most lightning EMP and EMC analysis. Because characteristic impedance is often not included in the wire specifications, the analyst or system designer frequently has difficulty obtaining this information. A good source of this information is laboratory measurements.

Two common methods for measuring characteristic impedance are time domain reflectometry and the propagation velocity method of IEC 96-1. Time domain reflectometry applies a fast risetime pulse to the transmission line and measures the reflected wave in the time domain. The propagation velocity method measures the capacitance and propagation velocity and calculates the characteristic impedance. Both of these methods measure the high frequency limit of the characteristic impedance.

With the advent of the microprocessor controlled impedance analyzers, such as the HP-4192A, another method for measuring characteristic impedance is now convenient; namely, the measurement of the resistance, inductance, conductance and capacitance of the cable sample as a function of frequency from 100 Hz to 12 MHz and the calculation of the characteristic impedance using the equation:

$$Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)}$$

The relative phase velocity and attenuation can also be calculated from the fundamental measurements.

In order to establish the credibility of the impedance analyzer method of measuring characteristic impedance, five cable samples were measured using the three methods.

All three methods of determining characteristic impedance yielded acceptable results. For values close to 50 ohms, all results were in good agreement; however, if the impedance is significantly different from 50 ohms, the uncertainties in the measurement become greater.

ANALYSIS OF THE EFFECTS OF CABLE PARAMETERS ON FIGURES OF MERIT SUCH AS "EMP RESPONSE"

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An approach to specifying shielding against transients, such as lightning and EMP, is to compute a figure of merit that combines or integrates a number of factors that are important to shielding using appropriate weighing factors. One such figure of merit is the "EMP Response" that is being used to specify shielded cable. The "EMP Response" is defined as:

$$\text{EMP Response} = -185 - 10 \text{ Log} \int_0^{4 \times 10^8} \frac{Z_t(f)^2 \, df}{(\alpha^2 + f^2)(\beta^2 + f^2)} \quad \text{(dB)}$$

where: $Z_t(f)$ = surface transfer impedance at frequency f (Ω/m)
$\alpha = 2.39 \times 10^5$, $\beta = 4.12 \times 10^7$, and f=frequency (Hz)

A typical specification states that this figure of merit must be greater than a certain value, such as 60 dB.

Cable designers normally design a cable to meet surface transfer impedance parameters, such as resistance and mutual inductance per unit length. How "EMP Response" depends on these cable parameters is not immediately obvious because of the number of variables involved in the calculation. This paper seeks to give the cable designer a feeling for what is important.

A computational model, called the skin depth/long line model, was developed that allowed the "EMP Response" to be calculated for arbitrary cable shield parameters (resistance and mutual inductance). Plots of "EMP Response versus either shield resistance or mutual inductance showed similar behavior. For resistances greater than 10 milliohms/m and mutual inductances greater than 600 to 700 picohenries/m the "EMP Response" is always less than 60 dB and would not meet the specification. For mutual inductances below 100 picohenries/m, the "EMP Response" is relatively independent of mutual inductance. Similarly, for resistances less than 3 to 5 milliohms/m, the "EMP Response" is relatively independent of shield resistance. Thus, the cable designer should attempt to design the cable shield with a resistance of less than 5 milliohms/m and a mutual inductances of less than 200 or 300 picohenries/m. If these conditions are met, production tolerances would not be critical. If the resistance or mutual inductance is outside of this range, meeting a 60 dB "EMP Response" specification is much more uncertain.

MEASURED TRANSFER IMPEDANCE OF METALLIC AND NON-METALLIC CONDUITS COVERED WITH TINNED COPPER AND SnCuFe BRAIDS

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The surface transfer impedance of 8 flexible conduits was measured over the frequency range of 1 kHz to 100 MHz using a 1.2 meter long quadraxial test fixture and two network analyzers controlled by a computer using the IEEE-488 buss. The samples included both brass and plastic conduits covered with various combinations of bronze, tinned copper and SnCuFe braids. These measurements showed that the tinned copper braid significantly improved the performance of the basic brass conduit covered with bronze braid. Adding a second layer of braid further improved the performance, especially above 100 kHz. Using SnCuFe braid as the intermediate layer resulted in improved performance between 10 kHz and 200 kHz.

Similar results were obtained for plastic conduits covered with tinned copper and SnCuFe braids with the exception that above 1 MHz these samples showed the typical mutual inductance coupling expected of braided cable rather than the very low transfer impedance, indicative of a solid shield, that is typical of a flexible brass conduit.

Interaction of High-Altitude Electromagnetic Pulse (HEMP)

with Transmission and Distribution Lines: An Early-Time Consideration*

K.S.H. Lee
F.C. Yang
N. Engheta

Abstract

In the first few tens of nanoseconds after an HEMP strikes the transmission and distribution lines of an electric power system, the induced transients on these lines rise to very high values. During these early times one cannot in general apply transmission line theory to calculate the transients. In this report a linear, time-domain scattering theory is employed to calculate such transients induced on a multi-conductor line above a finitely conducting ground. The relative importance of various inducing effects is discussed, which include the incident field, the fields scattered by neighboring conductors, and the field reflected from the ground. The effect of the conductor's resistivity is found to be negligible on the induced transients, whereas the incident field has the most dominant inducing effect. A formulation of the HEMP-induced corona on a wire is given with some introductory remarks.

The linear, time-domain scattering theory is applied to a typical 3ϕ, 765 kV transmission line and a 3ϕ, 13.2 kV distribution line. In the first 20 nanoseconds or so, the conductors of the transmission line can have induced currents of a few kiloamperes and the normal electric fields in the order of one-half megavolts per meter on the phase conductors and a few tens of megavolts per meter on the shield conductors. On the distribution line the induced currents are less by a factor of 5 to 6 but the electric fields are 5 to 6 times greater than those on the phase conductors of the transmission line.

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*This work was prepared for the Zaininger Engineering Company under subcontract to the Oak Ridge National Laboratory for the Division of Electric Energy Systems of the Department of Energy.

SIMPLIFIED METHOD OF SOLVING TRANSMISSION LINE NETWORK PROBLEMS

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Parviz Parhami, Ph.D
Jason Chai, Ph.D
TRW Inc., Redondo Beach, CA 90278

One method of solving a transmission line network problem, where many branches are involved, is to set up the network equations for the entire network. Each branch is described by the transmission line equation, and junction scattering matrix is used to describe the interconnection relationships of the branches. The currents and voltages of the network are solved by inverting the network matrix[1]. One drawback of this method is the necessity of using relatively large amounts of computer time. In EMP analysis and assessment, often it is not necessary to have high accuracy. Thus, reasonable approximations may be acceptable to solve such problems if they would significantly reduce computational efforts.

In this paper, a method of solving the transmission line network excited by electromagnetic fields by representing each branch by a Thevenin equivalent circuit is presented. Each Thevenin representation reduces one branch of the network, and successive applications of this procedure yields simple circuits around the point of interest, which can then be solved readily. This method is best suited to situations where responses at only a few points of the network are desired[2]. It has a considerable savings in computational effort over the network analysis technique. Furthermore, simple approximations can be used that greatly reduces the requirements of knowing the precise details of transmission line configurations, load values, etc. Bounds of the responses using these approximation procedures are established.

For a practical transmission line network in a complicated system, often the detailed information of the entire network is not known, particularly those branches far away from the points of interest. This often presents uncertainties in the calculated responses. The above method is extended to establish bounds in the responses when the branches far away from the point of interest are approximated. The methodology developed is useful in EMP system assessment.

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[1]F. M. Tesche and T. K. Liu, "User's Manual and Code Description for QV7TA: A General Multiconductor Transmission Line Analysis Code," Interaction Application Memo, August, 1978.

[2]T. K. Liu, "Solution of Transmission Line Networks by Branch Reduction Method," Report prepared for TRW Inc., under Subcontract No. PO2608AC2S, February, 1983.

SESSION F2
COMMUNICATIONS FACILITIES
Carrol Room
Chairman: Dr. J. Penar
TRW Inc., Redondo Beach, CA

1. 1:30 INVITED PAPER: EMP HARDENING OF TELECOMMUNICATIONS FACILITIES, J. MILETTA, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

2. 2:05 MEASURED AND PREDICTED HEMP-LIKE COUPLING RESPONSES PRODUCED ON A CONFIGURED GROUND COMMUNICATIONS FACILITY, V. Martins, XRI, Incorporated, Reston, VA

3. 2:30 EMP VULNERABILITY AND PROTECTION REQUIREMENTS OF UNINTERRUPTIBLE POWER AND ASSOCIATED SWITCHING EQUIPMENT, P. Dittmer, and E. Dorchak, BDM Corporation, McLean, VA

4. 3:15 EMP MITIGATION IN THE PUBLIC SWITCHED NETWORK I. RECONSTITUTION REQUIREMENTS, W. Herman, L. Albright, W. Rowland, J. Dancz, L. Miller, and A. Rausch, Booz, Allen & Hamilton, Inc., Bethesda, MD and C. Bodson, National Communications System, Washington, DC

5. 3:40 EMP MITIGATION IN THE PUBLIC SWITCHED NETWORK II: EVALUATION METHODOLOGY, J. Dancz, W. Rowland, W. Shiley, and A. Rausch, Booz, Allen & Hamilton, Inc., Bethesda, MD, and C. Bodson, National Communication System, Washington, DC

6. 4:05 PROJECTED HEMP COUPLING LEVELS BASED UPON MEASUREMENTS MADE ON A CONFIGURED GROUND COMMUNICATIONS FACILITY, V. Martins, XRI, Incorporated, Reston, VA

7. 4:30 SCALE MODEL BUILDING SHIELDING TEST RESULTS FOR HEMP-LIKE FIELD EXCITATIONS, V. Martins, XRI, Incorporated, Reston, VA

EMP Hardening of Telecommunication Facilities

Joseph R. Miletta
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The Department of Defense (DoD) is placing great emphasis on assuring the survivability of the national Command, Control, Communications and Intelligence (C^3I) resources to the electromagnetic pulse (EMP) produced by nuclear weapon bursts. This concern for survivability of telecommunications, which are characterized by extended networks, is well placed. Large transients can be generated on the conductive links between facilities and substantial electromagnetic fields can penetrate the existing facility structures. This threat becomes more ominous because the trend toward digital communications, encoded data and advanced microelectronics makes telecommunication systems more sensitive to electrical transients.

The objective of this paper is to provide an unclassified overview of the various techniques employed in telecommunications hardening. Approaches, (such as "tailored" versus "100 dB" methods) will be discussed in terms of the relative merit and application of each. Specific examples will be provided. It will be impossible to go into great detail in each area of hardening. The intent of the presentation will be twofold. First, telecommunications survivability can be achieved - EMP hardening is doable. Second, the costs associated with accomplishing this hardening are not excessive and there will be associated benefits (e.g., reliability and electromagnetic compatability).

MEASURED AND PREDICTED HEMP-LIKE COUPLING RESPONSES PRODUCED ON A CONFIGURED GROUND COMMUNICATIONS FACILITY

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XRI, Incorporated assisted Harry Diamond Laboratories in a theoretical and experimental program to develop HEMP hardening signal specifications based upon representative coupling levels to typical facility conductors. These specifications were requested by the Defense Communications Agency for application to future ground level based communications systems.

The verification tests were performed at the HDL Woodbridge facility using the REPS (horizontally polarized dipole type) and VEMPS (vertically polarized monopole type) simulators. The facility configured representative test elements consisted of overhead power lines, power lines in a buried conduit, associated power transformers, an overhead shielded telephone line, a buried shielded telephone line, a buried copper water pipe, an HF horizontal dipole antenna (100 ft in length), a fabricated radio tower (28 ft high), a 50x50 ft^2 - four inch thick cement test platform called the General Verification Facility (GVF) (this platform was rebar meshed and well grounded to the earth with ground rods every ten ft in all directions), a shielded cable between equipment racks, and a newly purchased 20x25x12 ft^3 metallic Butler Hut.

Test predictions were made for representative conductor/cable conditions and orientations (for both polarizations) and these were compared with the carefully collected test data. The comparisons were excellent, with amplitude deviations less than 20 percent, and quite good waveshape correlations. These comparisons then verified that the program developed HEMP coupling relationships could be applied in the generation of the HEMP signal specifications for DCA equipments. Selected results observed during the program representing the coupling reponses to typical facility conductors will be presented at the NEM Conference.

This work was sponsored by Harry Diamond Laboratories under Contract No. DAAK21-79C-0128.

EMP Vulnerability and Protection Requirements of Uninterruptible Power and Associated Switching Equipment

Dr. P. H. Dittmer and E. J. Dorchak, Jr.
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Advances in electronics have made it both desirable and possible to provide an electric power source for critical command, control, communications, and intelligence (C^3I) equipment which provides power that is constant in voltage and frequency regardless of disturbances or interruptions on external power. This paper considers a configuration of power and switching equipment typical of a C^3I facility. In most cases, this power equipment will be apart from the communications-electronics (C-E) equipment which it supplies so that it will not be encompassed by protection for that equipment, such as location within a shielded enclosure. Hence, EMP protection for this equipment must be designed separately, consistent with the level of protection afforded other system equipment.

Potentially vulnerable elements of the power system are presented together with the associated rationale for vulnerability. Emphasis is placed on uninterruptible power systems (UPS) and the automatic transfer switch (ATS) activating emergency backup power. Transient energy is introduced into the system through field diffusion and coupling together with long line coupling. Expected transient performance criteria based on manufacturers' specifications are cited and compared with transient protection requirements. Alternative methods for power system and equipment protection are described.

EMP MITIGATION IN THE PUBLIC SWITCHED NETWORK I. RECONSTITUTION REQUIREMENTS*

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The electromagnetic pulse (EMP) from a high altitude nuclear explosion has the potential to seriously degrade the performance of the nation's telecommunications network due to the EMP's wide area of coverage. In order to assure that requisite communications capability is available for necessary government functions after a nuclear attack, the National Communication System (NCS) has undertaken a number of programs to reduce the EMP vulnerability of the public switched network (PSN). One of these EMP mitigation efforts will be discussed in this paper (which will analyze reconstitution requirements) and in the accompanying paper (which will discuss a methodology for evaluating network EMP vulnerability). Future work is planned which will identify mitigation alternatives and assess their costs.

This study presents a methodology whose aim is to assess the vulnerability of the PSN and identify cost effective ways to mitigate these vulnerabilities. The major impediment to reconstitution is the highly hierarchical call routing schemes utilized in the PSN which will be severely disrupted by blast damage to urban areas. Being thereby forced into a requirement for nonhierarchical routing, attention is then given to mitigating vulnerabilities of the sites in that part of the PSN undamaged by blast.

Given such sites, there are certain functions which can be identified that are crucial to telecommunication operations; these functions have been used to identify critical facilities which must be considered in an EMP mitigation program. These critical facilities are: (1) switching, (2) signaling, (3) transmission, and (4) synchronization. A methodology for evaluating the EMP vulnerability of these critical facilities is presented in the accompanying paper.

There are many features of this EMP <u>mitigation</u> program which differ from traditional EMP <u>hardening</u> program which are noteworthy. They are: (1) the costs of making even minor changes in the large number of the nation's telecommunications facilities is potentially great, (2) the characteristics of the facilities and the potential EMP threat to those facilities may vary greatly from site to site, (3) the PSN is constantly undergoing upgrades and changes in technology which influence the EMP vulnerability, (4) existing repair and replacement practices can and will aid in the network reconstitution, and (5) alternate communications networks (satellites, microwave, etc.) are potential alternatives to this network reconstitution through low-level switching sites. It is felt that this program is unique in that cost/benefit analysis plays such a fundamental role in this EMP program.

* -Work has been sponsored by the National Communication System.

EMP MITIGATION IN THE PUBLIC SWITCHED NETWORK II, EVALUATION METHODOLOGY*

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In an accompanying paper, the requirements for reconstitution of the public switched network after a high altitude nuclear attack were analyzed and a general methodology was presented to assess the resulting vulnerability of the PSN. This present paper seeks to further develop that methodology and apply it by considering the switching facility for analysis. The intent here is to analyze this methodology and assess its effectiveness. This study will not attempt to evaluate network survivability nor will it analyze all appropriate critical facilities: additional efforts in this regard are planned.

This EMP evaluation methodology is primarily based upon analyzing requirements for conventional electromagnetic protection to natural (lightning) and man-made environments (EMC and EMI). The conventional protection so established is then compared to requirements for the EMP threat in order to relate the risk of the facility being vulnerable to the level of conventional protection. Such a relationship is useful for two reasons: (1) it simplifies the analysis of network vulnerability by relating such vulnerability to simple system descriptions of individual physical plants in the PSN and (2) it suggests techniques for improving the survivability of the PSN by improving and augmenting such practices.

This methodology, therefore, utilizes applicable standards and practices combined with facility EMP characteristics to evaluate critical facility vulnerability. These facility EMP characteristics are also derived from information concerning the physical plant housing the facilities, where applicable, which can be at least partially derived from information in the standards and practices and a knowledge of the EMP coupling to the system. This coupling will take the form of both long-line and local (shielding and aperture penetrations, etc.) coupling. These coupling and conducted transients are then compared to the conventional protection requirements to assess the risk associated with the facility EMP vulnerability. The results of this methodology applied to the test case of a switching facility will be presented.

* Work has been sponsored by the National Communication System.

PROJECTED HEMP COUPLING LEVELS BASED UPON MEASUREMENTS MADE ON A CONFIGURED GROUND COMMUNICATIONS FACILITY

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XRI, Incorporated assisted Harry Diamond Laboratories in a theoretical and experimental program to develop HEMP hardening signal specifications based upon representative coupling levels to typical facility conductors. These specifications were requested by the Defense Communications Agency for application to future ground level communications systems.

The program approach to the development of the signal specifications was based upon the "scientific method" where theoretical investigations of HEMP type coupling to conductors and cables (shielded and unshielded) were made that resulted in analytical expressions. These expressions in turn were used to plan tests, and evaluate the test data, which ultimately lead to their verification. These relationships were then used to generate the HEMP signal specifications.

The verification tests were performed at the HDL Woodbridge facility using the REPS (horizontally polarized dipole type) and VEMPS (vertically polarized monopole type) simulators. The facility configured representative test elements consisted of overhead power lines, power lines in a buried conduit, associated power transformers, an overhead shielded telephone line, a buried shielded telephone line, a buried copper water pipe, an HF horizontal dipole antenna (100 ft in length), a fabricated radio tower (28 ft high), a 50x50 ft^2 - four inch thick cement test platform called the General Verification Facility (GVF) (this platform was rebar meshed and well grounded to the earth with ground rods every ten ft in all directions), a shielded cable between equipment racks, and a newly purchased 20x25x12 ft^3 metallic Butler Hut.

Measured coupling levels will be presented at the NEM Conference for typical communications facility interfaces, as produced by the REPS and VEMPS simulators. These values serve as the basis for obtaining worst case HEMP coupling levels by factoring out the simulator's characteristics and replacing them by those of a worst case HEMP excitation.

This work was sponsored by Harry Diamond Laboratories under Contract No. DAAK21-79C-0128.

SCALE MODEL BUILDING SHIELDING TEST RESULTS FOR HEMP-LIKE FIELD EXCITATIONS

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This paper presents the results of measurements made upon 25:1 scale models of five building types whose walls and ceilings had no deliberate apertures nor external penetrators. The measurements were made at the Harry Diamond Laboratory Scale Model Facility (called the FREME) where the building models were placed over a large sand box and excited by horizontally and vertically polarized transient HEMP-like fields, as produced by specially designed dipole and monopole antennas.

Building shielding was defined here as the ratio of the total crest bulk current induced upon a representation of cables (run between a rack pair along with building's center) without and with the building present. The building dimensions modelled were based upon an existing Butler Hut (whose box like dimensions were $25x20x12ft^3$) at the GVF facility in Woodbridge, Virginia, where full scale simulator produced measurement data was also taken on the building.

The results show that a solid metal walled and ceiling building, where each wall is connected at their center to the screen floor (4 connections total) produced (as expected) the best shielding value of 15 db for both field polarizations. The next best was a building of fine mesh walls and ceiling where its wall extensions were buried in the equivalent of 3 ft. into the earth. Its shielding values were 12.8 db and 16.8 db for the vertical and horizontal field polarizations respectively. The worst case shielding observed was on a vertically rebarred wall building with a fine mesh roof and floor that were not electrically connected. The shielding value for this case were - 1.06 db and -2.21 db, or an enhancement of coupling to the interior cables for both field polarizations. Test data is also presented to demonstrate the shielding for various building foundation heights and electrical wall-to-screen floor connections.

This work was sponsored by Harry Diamond Laboratories under Contract No. DAAK21-81C-0131.

SESSION F3
SENSORS AND INSTRUMENTATION
Hanover Room
Chairman: Dr. F. J. Sazama
Naval Surface Weapons Center
White Oak, MD

1. 1:30 INVITED PAPER: TIME DOMAIN MEASUREMENT TECHNIQUES FOR E.M.P SIMULATION STUDIES, S. Cultrera and P. Papucci, C.A.M.E.N., Pisa, and B. Audone and G. Casalegno, AERITALIA, Turin, Italy

2. 2:05 B-DOT MICROPROBES, D. Ciarlo, D. Fromme, and K. Okubo, Lawrence Livermore National Laboratories, Livermore, CA

3. 2:30 A HIGH-SPEED, LOG-WEIGHTED PEAK LEVEL RECORDER, M. Gruchulla, EG&G WASC, Albuquerque, NM

4. 4:03 INVITED PAPER: A REVIEW OF THE EMP ACTIVITY IN ISRAEL, S. Eckhouse, Armament Development Authority, Haifa, Israel

TIME DOMAIN MEASUREMENT TECHNIQUES FOR E.M.P. SIMULATION STUDIES

by

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Abstract

The EMP requirements which were required on an optional basis for past projects of electrical and electronic equipments are now becoming more and more tight and essential.

In EMP studies it is necessary to perform time domain measurements and analysis.

These techniques have widened the spectra of measurement technology, especially with the development of new and sophisticated instrumentation which shall be completed by powerfull analysis tools.

A system is described for the analysis of transient phenomena: it is made of a digitizer connected to a computer having the capability of analyzing transients with different algorithms such as FFT, Prony's method and eigenvalues method.

The system is working in a small EMP simulator and is going to be used in a more complex facility.

Output data relative to simulation studies are presented. These studies have been undertaken to evaluate the EMP performances of new aircrafts in order to develop efficient hardening actions.

B-dot Microprobes*

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Abstract

We have designed and fabricated miniature sensors for the measurement of fast transient magnetic fields. These sensors, commonly called B-dot microprobes, consist of two small loops differentially connected for common mode noise rejection. Loop diameters from 0.2 mm to 5.6 mm have been used. The sensitivity of these probes is proportional to the product of the loop area and the rate of change of the magnetic field. Probes with sensitivities ranging from 7×10^{-8} volts/tesla/sec to 3×10^{-5} volts/tesla/sec have been fabricated. The frequency response of the probes approaches 1 GHz and is limited primarily by the off-chip connections.

We have used microfabrication techniques to fabricate these B-dot microprobes on ceramic substrates which are 1 inch by 1 inch and .01 inch thick. A laser is used to trim the ceramic after the probes are fabricated in order to minimize the amount of material in the probe region.

Three layers of aluminum metalization are used for the conductors and shielding. Polyimide layers are used for the dielectric. By using five micrometer thick polyimide, a signal voltage as high as several hundred volts can be tolerated.

We have used the NETTWO circuit code to simulate the electrical performance of these probes. Results of this simulation along with actual experimental data will be presented.

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

ABSTRACT ON
A HIGH-SPEED, LOG-WEIGHTED
PEAK LEVEL RECORDER

BY

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Digital acquisition of high-speed analog data (on the order of 100 MHz) is becoming increasingly popular with the availability of fast analog-to-digital conversion (ADC) devices. However, many applications such as quick-look survey, go-nogo testing, peak transient recording and others require detection of only the peak level of an event and all the structure information available from a high-speed ADC system may not be required. In those applications, a peak-level recording (PLR) system may provide a less complex, lower cost alternative to a high-speed ADC system. A PLR is basically a threshold detector with a number of discrete thresholds. There are numerous classic configurations for capturing peak signal levels. The technique discussed in this presentation is basically a variation of a flash converter. High speed comparisons are used which provide operation from DC to pulse widths on the order of 4 ns. The high capture speed is accomplished using a self-latching comparison configuration with minimum delay in the feedback path. Further, the switching thresholds are logarithmically weighted rather than the conventional linear weighting. Positive and negative peaks may be recorded with 40 dB of dynamic range, with 1 dB resolution, and with sign preserved (46 dB total dynamic range).

A review of the E M P activity in Israel

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The E M P activity in Israel in the last few years is mainly concentrated in the Electronic Defense industry.
Most of the work done in Israel is devoted to E M P analysis, developement of E M P simulation and testing techniques and E M P protection. A review will be given on some of the work done at the Armament Development Authority on Radiation mode simulators. Bounded wave and open wave simulators will be considered.

Work done on E M P direct drive injectors will also be described. Details of some of the injection systems developed and their application in E M P as well as in lightning effects simulation will be described. Some details of the design and operation of a multiple pin injection system will also be considered.

SESSION G1

SIGNAL PROCESSING AND DATA ANALYSIS

F. S. K. South

Chairman: N. Stetson

Naval Surface Weapons Center

White Oak, MD

1.
8:30 INVITED PAPER: A SURVEY OF PRACTICAL USES AND CONSIDERATIONS OF SINGULARITY EXPANSION FOR DATA ANALYSIS, M. Van Blaricum, General Research Corporation, Santa Barbara, CA

2.
9:05 EMP RESPONSE MEASUREMENTS AND SIGNAL PROCESSING, M. Crochet, Aerospatiale, Les Mureax, France

3.
9:30 USE OF DATA BASE MANAGEMENT SYSTEMS FOR STORING AND ANALYZING EMP TEST DATA, P. Parhami, J. Mosher, M. Wojtowicz, and C. Padgett, TRW Inc., Redondo Beach, CA

4.
10:15 SIGNAL PROCESSING OF TRANSIENT EM DATA, V. McGevna, Lawrence Livermore National Laboratories, Livermore, CA

5.
10:40 NOISE ESTIMATION OF MEASURED TRANSIENT RESPONSE DATA, L. Suarez, and W. Motil, TRW Inc., Albuquerque, NM

6.
11:05 A FAST AND ACCURATE ALGORITHM FOR COMPUTING MINIMUM PHASE, C. Padgett and P. Parhami, TRW Inc., Redondo Beach, CA

7.
11:30 A FRESH LOOK AT EXTRAPOLATION TECHNIQUES, P. Parhami and J. Brossier, TRW Inc., Redondo Beach, CA

A SURVEY OF PRACTICAL USES AND CONSIDERATIONS OF SINGULARITY EXPANSION FOR DATA ANALYSIS

Michael L. Van Blaricum
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Advanced Technologies Division
Santa Barbara, California

Over the last decade, the singularity expansion methodology (SEM) has given much insight into the physics of electromagnetic interaction phenomenon. This breaking down of currents and fields into natural resonances, modes and coupling coefficients has principally been used in association with numerical and analytical procedures. A lot of thought has gone into how SEM techniques can be used to aid in experimental "nuclear" electromagnetics data analysis. Such ideas include spectral analysis of data and instrumentation reduction as well as the development of complex lumped parameter systems models. In general, electromagnetics interaction with real systems cannot be modeled analytically or numerically. Therefore, in order to make use of these SEM tools, it is necessary to extract the SEM parameters directly from experimental data.

This paper will survey some of the uses of SEM for nuclear electromagnetics experimental data analysis which have been thought of over the years. In addition, a discussion of the state of the art of parameter extraction will be given. This discussion will include a look at signal processing techniques as well as some of the electromagnetic interaction physics which need to be understood in order to apply these techniques properly.

EMP RESPONSE MEASUREMENTS AND SIGNAL PROCESSING

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EMP response measurements for various systems must take into account some practical limitations such as

- Deviation between simulated field waveforms and EMP standards
- Poor signal to noise ratio of sensors transmission channels
- Spectrum notches of excitation signals

This paper first presents a brief review of limitations due to such practical matters in a system response identification

It shows how much a rough use of straightforward signal processing such as Fourier Transform can lead to considerable misunderstanding of a system response to a transient excitation.

Information and practical examples are given on the use of other signal processing techniques such a the z - transform Comparison of results of E.M. response of a test sample obtained by parallel use of FFT and z-transform shows numerous advantages (and some limitations) of the latter.

Practical algorithms and problems due to computation time duration for such transforms are discussed.

USE OF DATA BASE MANAGEMENT SYSTEMS FOR STORING AND ANALYZING EMP TEST DATA

Parviz Parhami, Ph.D
John Mosher
Michael Wojtowicz
Carl Padgett
TRW Inc., Redondo Beach, CA 90278

With the advance of EMP test instrumentation and techniques, an EMP system test can produce huge volumes of data overwhelming conventional analysis procedures. For example, during a typical aircraft test program, several reels of tapes are produced, each containing several hundred recorded waveforms. Sorting, processing and folding all these measurements with external information such as circuit functional analysis, threshold, interconnectivity, etc., can become a costly and frustrating experience.

Under the on-going Aircraft EMP Technology Program (ACEMPTD), a Data Base Management System (DBMS) is employed to store and control all phases of the latest aircraft test program. The DBMS contains all pre-test raw and processed data. In addition, the data base includes location information for all circuits within the aircraft as well as pin inter-connect data.

Even though this data base is in the early stages of evolution, it has demonstrated exciting new applications and produced interesting data analysis reports. Presented in this paper will be a report on the progress of this data base along with sample data analysis reports. Also discussed will be the current shortcomings of the data base, as well as possible future improvements.

SIGNAL PROCESSING OF TRANSIENT EM DATA*

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ABSTRACT

Coupling experiments are performed to measure the response of a specific test object and also to characterize the response of generic objects to EMP. The interaction of the EMP with these objects results in complex transients which present unique signal processing requirements. As the scope of EMP testing at LLNL has expanded, new signal processing techniques have been employed to analyze the diverse types of data obtained. Generally, the technique for processing a particular set of data is governed by the phenomena which is being studied. This paper will present a brief discussion of the following signal processing techniques which have been successfully applied to EMP data processing.

1.0 Model Estimation

A non-linear least squares output error identification algorithm has been developed at LLNL specifically for modeling transient data. It produces a model which can be used to characterize an object by its poles and residues, and has been used sucessfully to analyze electromagnetic transients. Generally the results obtained are more useful in understanding the underlying physics of the process being modeled than spectral analysis of the same data. Since the model fits a deterministic linear response to the data, it is robust against many types of noise in the measured data. It has also proven effective when the transient data available has not decayed to zero.

2.0 Power Spectral Density Analysis

One generic problem of interest is the coupling of EMP into a cavity through an aperture. The response within the cavity contains the superposition of many reflected waves, due to both resonances and random reflections. The random reflections represent a spatially stochastic process since the relative phase between two different reflected waves will vary with position. A stochastic process is characterized in the frequency domain by its power spectral density, PSD. The estimated PSD also gives a smooth estimate for the closely spaced spectral lines which are harmonics of the low frequency cavity resonances. This provides a simpler characterization of the cavity, and one which is less sensitive to changes in its size and shape.

3.0 Coherence Analysis

The coherence function is a frequency dependent correlation coefficient. Given two signals, the coherence is the ratio of the square of their cross power spectral density to the product of each individual PSD. If two signals are related by a linear transfer function then the coherence is one. If, however, these signals contain random noise or uncorrelated components then the coherence function becomes less than one. When the coherence is at or near zero, then the two signals are uncorrelated at those frequencies. This has been effectively used to establish some of the fundamental limitations in analyzing the experimental data.

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

ESTIMATION OF NOISE IN MEASURED TRANSIENT RESPONSE DATA

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One effect of system noise is to limit the frequency range where good information content occurs in the spectrums of measured transient responses. The difference between the statistics of the desired measurement and the system noise permits the estimation of the noise amplitude directly from the measured data without knowledge of the data recording system parameters. This quantification of the noise amplitude present in measured data has been accomplished through the application of R. W. Hammings[1] noise estimation technique. This paper describes a reliable noise estimation algorithm based upon this numerical technique. The algorithm developed is also shown to indicate the presence of other types of signal corruption as a result of aliasing or data system non-linearities. Such information can be utilized to evaluate the quality, and acceptability of measured transient response data. Examples of the algorithms performance for both analytic and real data are presented.

1. R. W. Hammings, "Numerical Methods of Scientist and Engineers". Second Edition. 1962

A FAST AND ACCURATE ALGORITHM FOR COMPUTING MINIMUM PHASE

Carl Padgett
Parviz Parhami, Ph.D
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In general, most linear signal processing problems require frequent use of Fourier/Laplace transforms. When dealing with real signals (causal), extreme care is required to avoid operations in the transform domain which could distort causality conditions. For example, multiplying a signal by only the magnitude of a filter in its spectral domain is guaranteed to result in an unrealistic and erroneous waveform.

The recorded data at EMP facilities typically go through a great deal of signal processing. Signal conditioners (filtering) are used to minimize noise, probe and instrumentation calibrations are folded into the waveform, and finally the signal is extrapolated to a threat defined in terms of a magnitude in the frequency domain. In order to preserve causality and ensure the final signal to be representative of actual EMP response, numerical phase reconstruction has become an important tool.

By definition, the minimum phase function is a class of functions with no zeros in the right-half plane. Most filter operations fall into this class of functions. An important property of minimum phase functions is that phase is uniquely related to its corresponding magnitude via the well-known Hilbert Transform relation[1]:

$$\text{Phase}\ (\omega_o) = \int_{-\infty}^{\infty} \frac{\text{Ln}\,[\,\text{Mag}(\omega)\,]}{\omega^2 - \omega_o^2}\, d\omega$$

A fast, efficient, and extremely accurate numerical procedure is introduced in this paper to evaluate the above infinite and singular integral. The procedure is based on Wiener-Lee transforms[1] combined with repeated use of Fast Fourier Transforms (FFT). Several examples will be presented to demonstrate the flexibility and applications of this algorithm.

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[1]Papoulis, Athanasios, "The Fourier Integral," McGraw-Hill Book Company, 1962.

A FRESH LOOK AT EXTRAPOLATION TECHNIQUES

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Jay Brossier
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Extrapolation techniques are often employed to adjust the measurements made at EMP simulators to a desired criteria response. The assumption of linearity is essential for the validity of any such operation. Therefore, EMP extrapolation is employed only when near threat simulators are used and only perform a second order correction to the recorded data.

Several types of extrapolation functions were introduced by Baum[1] and are the standard presently used in the community. Under the AirCraft EMP Technology Development (ACEMPTD) program, these extrapolation functions have been exercised for several aircraft over the period of three years. The result has been a steady improvement in the numerical algorithms used for deriving these functions as well as increased understanding of their limitations and advantages.

This paper presents a summary of the latest numerical algorithms employed for performing stable and causal extrapolation operations. Also discussed will be the theoretical limitations of these functions and the feasibility of designing advanced extrapolation functions.

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[1]C. E. Baum, "Extrapolation Techniques for Interpreting the Results of Tests in EMP Simulators, in terms of EMP Criteria," AFWL, SSN 222, March, 1977.

SESSION G2
SIMULATION AND SYSTEM TESTING
Carrol Room
Chairman: L. Diehl
Ideas, Inc., Beltsville, MD

1. 8:30 INVITED PAPER: TEST IN HARDENING DESIGN, C. Rodiere, Aerospatiale, Les Mureaux, France

2. 9:05 THE USE OF FAULT INSERTION TECHNIQUES IN EMP SYSTEM-LEVEL TESTING, P. Miller, and E. Chivington, TRW Defense Systems Group, Albuquerque, NM and M. Johnson, The BDM Corporation, Albuquerque, NM

3 9:30 SIMULATED EMP FIELDS WITHIN A METALLIC HANGAR, R. Perala, P McKenna, T. Rudolph, C. Easterbrook and S. Parker, Electro Mangetic Applications, Inc., Denver, CO

4. 10:15 INVITED PAPER: EMP SIMULATION BY PULSE INJECTION, Torbjörn Karlsson, Göran Undén, Linköping, Sweden

5. 10:50 LLNL TRANSIENT RANGE SHIP PHENOMENOLOGY EXPERIMENTS, K. Kunz, H. Hudson, J. Breakall and L. Spogen, Lawrence Livermore National Laboratories, Livermore, CA

6. 11:15 SCALE MODEL TESTING FOR EMPRESS II ANTENNA RESPONSE APPLICATIONS, L. Martin, and H. Hudson, Lawrence Livermore National Laboratory, Livermore, CA

7. 11:40 EXPERIMENTAL OBSERVATIONS OF THE ELECTROMAGNETIC COUPLING INTO A SLOTTED METAL BOX WITH AND WITHOUT A METAL OBJECT INSIDE, A. Cuneo, Jr., and J. Capobianco, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

Titre : *TEST IN HARDENING DESIGN*

Author : *Charles RODIERE*
AEROSPATIALE
78130 LES MUREAUX - FRANCE

The purpose of this communication is to present some difficulties that could be found in hardened systems test and how to prevent them.

It state two problems : first for the high level test, second for specification hardness.

For high level test, bigger is the specimen, bigger is the simulator. But so lacks in simulation may be come more important.

It is useful to have specification of hardness at the beginning of a design system. But at this time computation is not easy and expensive because design is complicated and in course of development. So it is useful to have a methodology that let write some specification.

To overcome these difficulties, we think it is possible to use several technics with a methodology.

Firstly by using processing signal we can have the real response of system for the good entrance data. Secondly with several synchronised simulators on the system it is possible to have a better simulation, and modulate the level. Thirdly by using scale model it is possible to get first specifications. The use of low level test is possible to ensure a good caracterisation and check specification and purpose high level test.

Now it is also necessary to take in account others ambinaces like ligthening and realize a synthese between them.

THE USE OF FAULT INSERTION TECHNIQUES IN EMP SYSTEM-LEVEL TESTING*

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In the past, typical free-field EMP testing has involved the collection of EMP response data on an unmodified test object. This can unnecessarily confine the objectives and outputs of the test. The usefulness of free-field testing can be dramatically extended with the application of intentional shield-faulting techniques. Deliberate fault insertion results in a known, degraded condition of the test object which can then be exploited to obtain unique system-level performance data. Some of the uses for this data include:

- Development of a Hardness Maintenance data base--such as the determination of which fault locations are the most important to control;
- Determination of the relative importance of uncontrolled layers of shielding topology to the overall shielding effectiveness; and
- Determination of in-situ system-level upset threshold margins under free-field conditions.

In addition, several transient propagation effects and system isolation/cross-coupling parameters can be investigated. Representative test data will be presented to exemplify these and other interesting uses of the fault insertion technique. Proven, low-cost fault insertion methods and hardware will be described and their limitations discussed.

*Work performed under Contract Number F04704-83-C-0028.

SIMULATED EMP FIELDS WITHIN A METALLIC HANGAR

By

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ABSTRACT

At the present time, threat level EMP illumination tests of large systems are conducted at outdoor simulation facilities. Test time at these facilities can be very expensive, and test days lost because of bad weather conditions can significantly impact the cost of a test. It is for this reason that there is interest in developing an indoor EMP threat level field illumination facility.

Such a facility has been proposed to be developed in a large blimp hangar at the Naval Air Engineering Center (NAEC) in Lakehurst, N.J. Unfortunately, this hangar has a metal roof. In this paper, we discuss the effects of this metal roof upon the fields in the test volume, and in particular discuss it's interesting focussing properties for different polarizations. Ways of reducing reflections from the roof are examined, and analytical results are compared with experimental measurements.

EMP SIMULATION BY PULSE INJECTION

Torbjörn Karlsson and Göran Undén

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Current injection in order to simulate EMP effects is important as part of the EMP validation process. While being the predominant test method during the development phase or the construction period of a system, pulse injection has not been considered useful for acceptance tests. However, if it is used in conjunction with free field simulation and well designed supporting analyses, pulse injection techniques promise to emerge as suitable tools for system testing during the production and the deployment phases as well.

With the objective of developing a useful technique for pulse injection into buried structures and other large objects not suited for tests in EMP simulators, FOA has carried out a series of experiments. The pulse generators used in the three experiments mentioned below were simple laboratory models.

A power plant was the object for pulse injection on aerial power lines. Pulse propagation inside the plant was studied. The injection method was analysed with respect to simulating a calculated EMP current from the power lines as well as the effect of the EMP current inside the plant.

In order to evaluate the quality of EMP hardened cable vaults a simple injection line was constructed consisting of a 60 cm steel tube, ten meters in length, in which the cables were centered. At one end, a pulse was injected onto the cables and at the other end the tube was circumferentially connected to the shield around the cable entry. Experiments show that this device is useful for testing both hardening design and components used in the installation.

Almost the same method can be used to determine the transfer impedance of braided shielded cables. An experiment will be described where a cable was centered in a 10 cm tube, five meters in length. A current pulse was driven on the cable shield which was terminated with a matched load at the far end of the tube. Transferred voltage on the internal conductors was measured by using a microwave link which was necessary in order not to disturb the termination.

Conclusion: A low budget program containing simple laboratory models can be used in order to obtain fairly accurate hardening validation.

LLNL TRANSIENT RANGE SHIP PHENOMENOLOGY EXPERIMENTS*

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Currently the Navy is preparing to test naval vessels with a vertically polarized simulator mounted on a floating barge. A series of scale model ship tests, using the HMCS Huron model, were performed at the LLNL transient range to gain a phenomenological understanding of the coupling mechanisms possible with such a simulator. This could then be compared to the totality of coupling mechanisms possible with ships, allowing an evaluation of the capability of this simulator to provide representative ship responses. Of particular interest was the necessity of a horizontally polarized simulator.

LLNL found from vertical and horizontal polarization tests that most major resonances of the entire ship and of ship structures were most strongly excited vertically and that no half wavelength resonance of the ship's hull could be exicted vertically or horizontally because of the perfect ground plane upon which the ship rested. It was concluded that the vertical mode of simulation should be preferred over horizontal when only one polarization may be treated. However, some smaller structures are excited to comparable levels by horizontal simulation. Therefore, for completeness, horizontal simulation at high frequencies, where such structures resonate, should be performed.

The transient range ship phenomenology experiments showed the following features for the structures measured, in particular, the ship mast and the wires connecting elements on the mast to control rooms and a mast mounted antenna:

- Even order harmonics are appreciably excited on the mast - symmetry breaking geometry of actual system, that cannot be avoided in practice, insures this.
- Wire response signature is determined by only a few factors - length, terminations, orientation, and immediately adjacent structures.
- Resonance sharing does occur, but weakly - antenna resonance seen in the mast response for horizontal polarization, for example.
- Wire response is nearly the same inside and outside the ship - true at lowest resonances, some attenuation of high frequency resonances on the wire outside the ship.

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

Scale Model Testing for EMPRESS II Antenna Response Applications*

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Electronics Engineering Department
Lawrence Livermore National Laboratory

Abstract

The EMPRESS II EMP simulator design concept includes a barge-mounted vertically polarized conical antenna. The concept is based on the VPD-II EMP simulator located at Kirtland AFB, New Mexico. The EMPRESS II antenna is conical in shape as approximated by a hexagon in the horizontal cross section. A scale model was constructed and testing was performed to support computer code development for prediction of the antenna response characteristics. The conical section was mounted on a scale model of the barge. Tests were performed on the LLNL electromagnetic transient test range facility which permitted computation of scale model impedance from the test data. These results compared favorably with those obtained from a separate compute code simulation.

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

EXPERIMENTAL OBSERVATIONS OF THE ELECTROMAGNETIC COUPLING INTO A SLOTTED METAL BOX WITH AND WITHOUT A METAL OBJECT INSIDE

by

Andrew A. Cuneo, Jr.
Joseph Capobianco

In support of the electromagnetic pulse (EMP) evaluation of the Hardened Tactical Shelter (HATS), a scale model (1/10) study was initiated to experimentally observe the electromagnetic coupling into the interior of a metal cavity through a horizontal slot. The model was driven by a vertically polarized electric field inside a parallel-plate transmission line. A magnetic-field sensor was placed in the line to measure the field in the absence of the cavity. Then the same sensor was placed inside the cavity, on the floor behind the aperture. The ratio of external magnetic field to internal magnetic field is computed over the frequency range from 100 MHz to 1.0 GHz using swept frequency sources, power amplifiers, and a spectrum analyzer.

Some observations drawn from this work follow:

1. There are portions of the spectrum where the internal field is greater than the external field.

2. Introducing a metal object into the center of the cavity changes the character of the frequency response.

3. There is not, in general, a dramatic difference between the internal field for the case of the cavity grounded at one point and for the cavity totally in contact with the ground.

SESSION G3
CABLE TESTING

Hanover Room
Chairman: L. Martin
Lawrence Livermore National Laboratories
Livermore, CA

1. 8:30 THE RELATIONSHIP OF BULK CIT TO EMP EXCITATION, J. Tigner, D. Frederick, P. Setty and R. Sutton, Science Applications, Inc., McLean, VA

2. 8:55 MEASURED TRANSFER IMPEDANCE OF A LARGE GRAPHITE-EPOXY COMPOSITE TUBE WITH CURRENT DIVERTERS, L. Hoeft, V. Gieri and J. Hofstra, The BDM Corporation, Albuquerque, NM

3. 9:20 TRANSIENT COUPLING INTO CAVITY-BACKED APERTURES, J. Breakall, J. Morrison, G. Hudson and R. King, Lawrence Livermore National Laboratories, Livermore, CA

4. 10:15 RELATIONSHIP OF SHIELDING EFFECTIVENESS TO TRANSFER IMPEDANCE/ADMITTANCE FOR CABLE EMISSION AND SUSCEPTIBILITY, R. Peel, Martin Marietta Aerospace, Denver, CO

5. 10:40 TRANSFORMER COUPLED CURRENT DRIVES FOR BURIED CABLES, H. Aslin, Physics International Company, San Leandro, CA

6. 11:05 EMP/PLUME COUPLING, M. Price, Electro Magnetic Applications, Inc., Huntsville, AL

7. 11:30 SHIELDING EFFECTIVENESS FOR NEMP OF DOUBLE SHIELDED CABLES WITH INTERMEDIATE DIELECTRIC LAYER, J. Weissman and B. Z. Raisch, Armament Development Authority, Haifa, Israel

THE RELATIONSHIP OF BULK CIT TO EMP EXCITATION

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In order to establish simulation fidelity requirements for the electromagnetic pulse (EMP) excitation of aircraft cables by the use of bulk current injection testing (CIT) techniques, it is important to quantify the relationship between the bulk cable current and individual pin current for a variety of excitation processes. The determination of this relationship is complicated by the extreme complexity of typical aircraft cabling, both in the nature of the electromagnetic shielding topology commonly employed and in the fact that such cables consist of a large number of wires with many branches and breakouts, terminated in a variety of load impedances. The difficulty in these analyses is further compounded by the fact that the source of the EMP excitation at the pin level is very often not well known; there may be a variety of drive mechanisms each contributing comparable signals at the pin level each with its own unique bulk/pin current relationship.

In this paper, we will present the results of model calculations of the response of typical aircraft cable configurations to a variety of excitation mechanisms. The cable configurations chosen for this analysis are of sufficient generality to encompass all material and geometric variations of typical aircraft cables; we have considered multiconductor cable configurations with a variety of cable shielding topologies. In addition, we have considered a number of different drive mechanisms associated with the EMP excitation and CIT techniques, ranging from a distributed electric and magnetic field excitation to bulk current injection and end point excitation. These calculations have been performed using a series of analysis tools discussed in papers presented at the 1982 NEM Conference.[1,2] The foundation of this approach rests on the ability to calculate the distribution of Norton and Thevenin equivalent source terms for abitrary multiconductor cable configurations for arbitrary excitations which, in combination with a multiconductor transmissionline code, can be used to determine the distribution of pin signals at box interfaces. The objective of these calculations will be to determine the sensitivity of the simulation fidelity parameters to reasonable variations in the model inputs (shielding, topology, excitation source, etc.).

REFERENCES:

1. "Electromagnetic Coupling through Cable Shields", P. N. Setty and J. E. Tigner, Session NEM-1, Paper No. 1, presented at the 1982 Joint USRI/APS/NEM Meeting, May 1982.
2. "The Coupling of Electromagnetic Fields to Multiconductor Cables", J. E. Tigner and D. F. Frederick, Session NEM-4, Paper No. 4, presented at the 1982 Joint USRI/APS/NEM Meeting, May 1982.

MEASURED TRANSFER IMPEDANCE OF A LARGE GRAPHITE-EPOXY COMPOSITE TUBE WITH CURRENT DIVERTERS

L. O. Hoeft, V. A. Gieri and J. R. Hofstra

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Composite materials are being used more frequently in advanced aerospace systems. This use led to concerns about their ability to shield against electromagnetic fields and carry large currents generated by lightning or EMP. This study explored this problem by measuring the transfer impedance of a 49-inch long, 11.5-inch diameter, 0.1-inch thick sample of graphite epoxy composite tubing. Besides measurements of the composite tube itself, several configurations were measured in which 5/8-inch O.D. copper pipes were placed on the exterior and interior surfaces of the composite tube to explore how currents would flow on structures made with both composite and metal current paths.

The composite tube was made into a 50-ohm transmission line by inserting a metal cylinder into the center of the tube. A special quadraxial test fixture was built to accommodate the sample and the surface transfer impedance was measured using procedures normally used for cable measurements. A computer-controlled data acquisition system was used to make the measurements from 10 Hz to 100 MHz.

The measured transfer impedance of the composite tubing without diverters displays the classic shape expected of a solid cylindrical shield. This suggests that graphite-epoxy acts like a homogeneous material. The d.c. resistance and break frequency are consistant with a homogeneous material with a conductivity of 2×10^4 mhos/m. The addition of 4 copper pipes to the exterior significantly lowered the low frequency transfer. However, it begins to increase at 100 Hz and by 30 kHz the effect of the diverters has disappeared. This is consistent with earlier measurements of cableways with aluminum sides and a steel top and bottom. Similar measurements explored the effect of internal current diverter and joint impedance.

These measurements suggest that: (1) graphite-epoxy behaves like a homogeneous material with a reasonable conductivity; (2) current diverters are relatively ineffective for fast risetime currents such as lightning and EMP; and (3) joint impedance was important at frequencies above 1 MHz.

Transient Coupling Into Cavity-Backed Apertures*

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Abstract

Experimental techniques and results are presented for electromagnetic coupling to test objects at frequencies up to 2.5 GHz. The LLNL EM transient range (which has been extensively used to test scale models of aircraft, ships, and EMP simulators) was used for these present coupling measurements. Extensive experiments have been conducted on aperture coupling into cavities with and without wires inside. Excitation was provided with a very short 1 kilovolt pulse (370 ps) radiated from a 3m high monocone antenna over a 10 x 10m ground plane on which the test object lies. Results were obtained using extensive data acquisition and signal processing capabilities which have been developed over the past several years. Considerable insight into individual system parameters has been obtained from the separation of coupling effects due to the aperture, the cavity, and the wire inside. It was found that the lowest frequency where significant coupling occurs is where the aperture circumference is about one wavelength. Also, the aperture Q is greatest for apertures having a large aspect ratio. Power coupled to a wire inside a cavity decreases as the wire moves further away from the aperture. The transfer ratio near the aperture can exhibit gain, i.e., fields just inside the aperture can be greater than the incident field. The physical properties of the aperture produce the most significant coupling effects as compared to those of the cavity and wire. Discussion of the extension of this work to more complicated structures is also given.

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

RELATIONSHIP OF SHIELDING EFFECTIVENESS TO TRANSFER IMPEDANCE/ADMITTANCE FOR CABLE EMISSION AND SUSCEPTIBILITY

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A continuing controversy exists between the EMP and EMC communities over how to define the electromagnetic shielding capabilities of cable shields. EMP engineers use transfer impedance and admittance, Z_t and Y_t, while EMC engineers use shielding effectiveness, SE, to describe a cable shield's electromagnetic attenuation capability. For virtually all strategic system development work, the EMP and EMC shielding requirements must be compared to achieve an adequate cable design. Understanding of the relationship between these parameters is presently needed.

This paper presents conversion relations between these shielding parameters for both the cable susceptibility and emission cases. Though these conversion relations are for the electrically short cable case (i.e., cable length is much less than the wavelength of interest), the physics of the cable coupling or emission is directly applicable to the electrically long cable case.

This paper also describes a series of cable radiated susceptibility and emission tests which verified the above conversion relations and the corresponding physics effects. Both coaxial and twisted shielded pair cable types were tested. The tests were conducted at an open field site which allowed measurement of field strength without the complication of shielded room reflections.

Among the results and conclusions derived from this work are the following:

(1) A marked degree of reciprocity was demonstrated between the susceptibility and emission cases.

(2) Shielding effectiveness for electrically short cables was shown to be independent of cable loads. This is at variance with an existing rule of thumb commonly cited in the literature. Use of this community rule of thumb can lead to an overestimate of true shielding effectiveness by 50 dB or more at low frequencies.

(3) Since EMP and EMC shielding parameters were related for both susceptibility and emission cases, selection of a single shielding parameter to characterize (standardize) cable shielding performance is possible. Also, a single test for this parameter is all that is necessary for design verification.

TRANSFORMER COUPLED CURRENT DRIVERS

FOR BURIED CABLES

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There exists a need for equipment to drive current pulses onto cables or bundles of cables buried in the earth medium. And, since, in many cases the conductors link various parts of an operating facility, there exists the further requirement that the pulse source be coupled in a way which results in minimal physical disturbance of the cables and their terminations. One immediately evident approach is the use of transformer coupling where the transformer is separable into halves which can be clamped around the cable over a short length which has been exposed to gain the necessary access.

The subject of this paper is the design of transformer coupled current drivers, or, more appropriately, voltage injectors, beginning with an assessment of the "load impedance" as functions of the properties of the earth medium and the physical and electrical characteristics of the driven cable. This is followed by a detailed description of a particular transformer coupled pulse generator design; a design intended to inject fast rising ($\sim$20 ns - 10-90%), 300 ns (RC) wide, 100 kV pulses onto buried cables with a pulse shape which approximates a double exponential. The point design in this case is a vehicle for the discussion of relevant transformer parameters, and techniques including: saturation induction, pulsed permeability, core bias, leakage inductance, and electrical insulation considerations.

EMP/PLUME COUPLING TEST

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An EMP simulator was used to generate pulses before, during and after a solid rocket horizontal static test firing to measure RF coupling onto downstage cables. Seven pulses per second were generated producing an EMP electric field of about 650 V/m at the location of the plume. Measurements were made of cable currents using two separate cables--one consisting of twelve twisted shielded pairs (Cable 1) and the other consisting of eleven twisted pairs (unshielded) and one coaxial cable (Cable 2). Common mode signals were obtained either by connecting all of the shields together for Cable 1 or by connecting all of the wires together for Cable 2. The rocket engine burned for 1.6 seconds and a total of eight pulses were recorded during this time. By comparing these data with measurements made immediately prior to and after the firing, we determined that the maximum value for the average conductivity of the plume was less than 10^{-2} mho/m, according to a simple plume conductivity model. For this particular solid rocket engine, the EMP/plume coupling increase in the induced cable currents was negligible.

SHIELDING EFFECTIVNESS FOR NEMP OF DOUBLE SHIELDED CABLES WITH INTERMEDIATE DIELECTRIC LAYER

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ABSTRACT

NEMP induced currents on the shield of Coaxial Cables cause a voltage in the center conductor. The induced current on the shield depends on the peak amplitude and rise time of the NEMP, electric properties of the ground, cable characteristics and the circuit connected. Once the shield curent is known, the induced voltage can be determined using the transfer impedance - Z_T. The measured transfer impedance - Z_T and transfer admitance Y_T of various double layer shielded cables, with and without intermediate dielectric layers, show a significant improvement in the screening of NEMP, when dielectric layers are used.

SESSION H1
EQUIPMENT ASSESSMENT
F. S. K. South
Chairman: J. Peneau
Aerospatiale, Les Mureaux, France

1.
1:30 INVITED PAPER: PRACTICAL MEASUREMENTS WITH A SPECIAL 600 kV MULTIPLE IMPULSE NEMP TEST SYSTEM, M. Lutz, E. Gockenback and O. Frey, Emile Haefely Co, Ltd., Basel, Switzerland

2.
2:05 THE MEASUREMENT OF RESPONSE TIME SURGE PROTECTION DEVICES USING HIGH POWER TIME DOMAIN REFLECTOMETRY, W. Davidson, Marconi Space and Defense Systems Limited, Camberly, Surrey, UK

3.
2:30 CURRENT INJECTION METHODS ON CABLES AND EQUIPMENT, J. Peneau and M. Crochet, Aerospatiale, Les Mureaux, France

4.
3:15 EMP TEST METHODS FOR AVIONIC EQUIPMENT AND THE IMPLICATIONS FOR TEST SPECIFICATIONS, J. Bishop, Royal Aircraft Establishment, Farnborough, Hants, UK

5.
3:40 A PORTABLE PROGRAMMABLE PULSER FOR DIRECT DRIVE TESTING, J. Gibson, EG&G WASC, Albuquerque, NM

6.
4:05 EMP VULNERABILITY AND PROTECTION OF DIESEL GENERATOR SET, G. Jellison, The BDM Corporation, McLean, VA

7.
4:30 THE PEAKING CIRCUIT REVISITED, J. Harrison, Maxwell Laboratories, Inc., San Diego, CA

Practical measurements with a special 600 kV multiple impulse NEMP test system

M. Lutz, E. Gockenbach, O. Frey
EMILE HAEFELY & CO.LTD., Lehenmattstrasse 353
Basel/Switzerland

This paper describes a test system with the capability to generate multiple NEMP pulses up to 500 kV and rise times $\leq$ 5 ns. A multiple impulse can consist of a maximum of 10 single impulses. The minimum time interval between two successive impulses is between 10 and 20 ms which equals a pulse repetition frequency of 50 to 100 Hz.

The high voltage circuit is built of three main components: Marx-Generator, separating device and peaking circuit with the antenna connected to it.

The entire energy needed for the max. 10 impulses is stored in the Marx Generator. A specially designed spark gap which will be described in detail in the paper allows that only part of that total energy is delivered to the peaking circuit and its capacitors.

A separating device, basically a high voltage diode prevents that the peaking circuit capacitor is discharged again via the Marx Generator circuit.

The peaking circuit with the antenna has been designed so that rise times of $\leq$5 ns are possible. A triggered spark gap built into the peaking circuit allows to operate the whole system with a jitter below $\pm$ 25 ns.

Further to the measuring results the paper will also describe which major problems had to be overcome while operating the system.

Multiple NEMP type impulses could serve to simulate the situation occurring when missiles with nuclear warheads are intercepted in high altitude.

Enclosure: photograph of the peaking circuit described in this paper.

THE MEASUREMENT OF RESPONSE TIME OF SURGE PROTECTION DEVICES USING HIGH POWER TIME DOMAIN REFLECTOMETRY

W.Davidson: Technology Group, Marconi Space and Defence Systems Limited, Chobham Road, Frimley, Camberley, Surrey, United Kingdom, GU16 5PE.

This paper describes a test programme undertaken by MSDS Limited for the UK MOD to evaluate the performance of surge protection devices when exposed to voltage pulses with leading edge rates of rise typical of nuclear electromagnetic pulses.

The method used was that of high voltage time domain reflectometry poineered by J.D.R. McQuillan (Reference 1). Principal characteristics of the equipment which was specially designed and built for this purpose were:

Peak Voltage:	variable up to 8kV
Pulse Duration:	variable up to 2μs
Pulse Rise Time:	variable 0.3ns to 400ns

The paper describes the equipment design theory and practice. It is shown that it is possible to measure time-to-switch and switching voltage of surge suppression devices. In addition the statistical spread of spark gap breakdown voltage and time and variation in glow-to-arc transitions can be measured. All these measurements were feasible with modest voltage pulses because of the very high rates of voltage achievable. One important feature of the design is the incorporation of a capacitor probe some distance from the device under test thus enabling the incident pulse and device response to be separated in time.

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

The kit was used to measure the characteristics of a wide range of components including spark gaps, TAZ diodes, varistors, filters and hybrid units. The paper presents test results on many of these components and discusses the results.

The work is fully described in the following references:

1. McQuillan J.D.R., 'The use of high powered TDR in the characterisation of protective devices'. Unpublished MOD(PE) Report, September, 1979.

2. J.A. Fryer and P.R. Miller, 'The application of surge protection devices for NEMP hardness assurance. A survey of device testing methods' - MSDS Report T(F)M/744.

3. P.R. Miller and C.P. Corr, 'The application of surge protection devices for NEMP hardness assurance'. MSDS/NS Guide No. 6.

CURRENT INJECTION METHODS ON CABLES AND EQUIPMENT

Authors : J.M. PENEAU - M. CROCHET
AEROSPATIALE - 78130 LES MUREAUX

The aim of this paper is to show the validity, the limits and the various test set-up configurations for current injection on pieces of electronic equipment interconnected by shielded or non shielded cables.

After a brief review of typical current waveforms to be simulated, we can show how it is possible to design and build up a test set up taking into account the practical limitations and availability of pulse generators.

Several exemples of practical design are given for various cases :

- completly shielded cables and equipment, by means of direct drive or current transformer injection
- unshielded cables (current transformer coupling)
- direct drive of equipment inputs

Emphasis will be made on two important points :

- understanding of the behaviour of the coupling network including : pulser, coupling device and tested circuity, and computer aided design of the test set up
- common mode to differential mode conversion on multiple entry equipment and practical ways to achieve such a coupling

EMP TEST METHODS FOR AVIONIC EQUIPMENT AND THE IMPLICATIONS FOR TEST SPECIFICATIONS

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One of the requirements for the production of EMP hardened aircraft or the assessment of EMP vulnerability is to test avionic equipment against an EMP test specification. The paper describes methods of bulk current injecting simulated EMP induced currents on to equipment cables, methods of measuring voltages appearing at components within the equipments and methods of measuring the coupling impedances between the cables and components. Also described are methods of making and the results of low level swept cw measurements; these form the initial part of an EMP vulnerability assessment programme.

Measurements on avionic equipments have shown the value of bulk current injecting low level swept cw current on to equipment cables, and the simultaneous measurement of induced voltages at test points within the boxes. This is shown to provide a realistic assessment of the voltage induced by a high level damped sinusoidal impulse. It is also shown that the cable to component coupling varies significantly between components and that the magnitude of the impedance is not necessarily a smooth function of frequency.

A further use of swept cw measurements described was to measure the equipment cable loop impedance using a current transformer and a simple pickup loop. These measurements if made initially on an aircraft and then repeated on the equipment test set up show the differences between the two. It is then possible to alter the cable impedances of a laboratory or avionic rig to match those of the aircraft, thus ensuring that a non aircraft test is as realistic as possible.

The paper concludes that with injected cw it is possible to test avionic equipments at low level thus avoiding any possibility of causing damage, to predict with reasonable accuracy the results of injecting a high level damped sinusoidal transient and to modify a test rig so as to make the cable impedances a better approximation of an aircraft. The coupling measurements have shown that in order to properly test an equipment it is necessary to inject damped sinusoids over the whole of the expected threat frequency range, rather than at some arbitrarily selected spot frequencies.

ABSTRACT ON A PORTABLE PROGRAMMABLE PULSER FOR DIRECT DRIVE TESTING

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Direct-drive testing of equipment and systems is gaining popularity for determining levels of upset and damage due to various transients to which the units may be subjected in actual use. A variety of custom test equipment has been developed with typically limited ranges of capability for support of very specific tests. In this presentation, the design and operation of a portable programmable pulser (P^3) is presented. The basic P^3 system consists of a system control unit, waveform generator (damped sine for example) and two 1kw linear power amplifiers. The use of the linear power amplifiers provides a wide range of versatility to the system. Virtually any waveform within the frequency range of 1 kHz to 200 MHz may be processed through the amplifier system. The system gain is about 60 dB and is variable in 0.1 dB steps over a range of 80 dB. A drive of 0 dBm is required for full output simplifying the design of the waveform generation circuitry. The basic waveform generator included is a damped sine unit with a frequency range of 10 kHz to 100 MHz and continuously variable damping time constant of 50 ns to 10 ms. The system control unit provides a variety of functions including an auto-cal. A fiber-optic RS-232 link is included to allow isolated control and monitoring of the P^3 system from a remote computer.

EMP Vulnerability and Protection of Diesel Generator Sets

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The BDM Corporation, 7915 Jones Branch Drive, McLean, VA 22102

The EMP vulnerability of large diesel generator sets, of the type used for standby electric power generation, is evaluated. A number of vulnerable components are identified. The governor, for example, would need about 45 dB of voltage attenuation if it is electronic; a hydraulic governor would be EMP-hard. Semiconductor components in the generator itself may be exposed to line surges or to internally coupled EMP. The vulnerability of the exciter field diodes, voltage regulator, and other components is discussed. Available EMP hardening technology is evaluated for cost, maintainability, and suitability to diesel generator protection.

THE PEAKING CIRCUIT REVISITED*

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San Diego, California 92123

John L. Harrison

ABSTRACT

The peaking circuit has been extensively used in NEMP simulators. The ideal output waveform for these simulators is a fast-rising, double exponential pulse. This paper develops a set of equations that can be used to calculate the value of the peaking capacitance, and the switching time for a circuit with inductance and resistance in the three legs of the circuit. While the solution does not provide a closed-form solution for these two unknowns, it provides a set of simultaneous equations that can be solved using a calculator or a computer.

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Kirtland Air Force Base, NM 87117

Air Force Ballistic Missile Office
Air Force Systems Command
Norton Air Force Base, CA 92409

SESSION H2
HARDNESS PROTECTION AND MAINTENANCE
Carrol Room
Chairman: J. Gut
Research Institute for Protective Construction
Zurich, Switzerland

1. 1:30 INVITED PAPER: COMPUTERIZED EMC ANALYSIS, K. Siarkiewicz, RADC, Griffis AFB, NY

2. 2:05 PROTECTION AGAINST TRANSIENT CURRENTS (EMP) ON MULTICONDUCTOR TRANSMISSION LINES, J. Haseborg, and H. Trinks, Technical University Hamburg-Harburg, R. Sturm, NBC Defense Research and Development Institute, Munster, Federal Republic of Germany

3. 2:30 HARDNESS MAINTENANCE EXPERIENCES ON EMP PROTECTION EQUIPMENT, R. DeKalb and J. Whitt, Teledyne Brown Engineering, Huntsville, AL

4. 3:15 INVITED PAPER: EMP HARDENING FEATURING INTERACTIVE GRAPHICS AND COMPUTER AIDED DESIGN, D. White and M. Mardiaguian, D. White Consultants, Gainsville, VA

5. 3:50 USE OF FILTER PIN CONNECTORS FOR EMP PROTECTION, J. Mosher and P. Parhami, TRW Inc., Redondo Beach, CA and J. McCormack, McDonnel Douglas Aircraft Corp., St. Louis, MO

6. 4:15 EMP COUPLING SOURCE HANDBOOK FOR ARMY SYSTEM DEVELOPERS, K. Lepoer, ERADCOM, Harry Diamond Laboratories, Adelphi, MD

COMPUTERIZED EMC ANALYSIS

Kenneth R. Siarkiewicz
Rome Air Development Center
Griffiss AFB, NY 13441

The Air Force has developed a set of computerized mathematical models to be used by military and industrial agencies to increase the assurance of system level electromagnetic compatibility (EMC) among the components of complex AF systems. These codes are applicable to aircraft, ground, and space/missile systems whether under development or undergoing modification. These codes provide a means for directing attention to the most likely sources of EMC problems, resulting in an effective use of funds allocated to system integration and EMC testing.

The main analysis codes that are available are:

(1) Intrasystem Electromagnetic Compatibility Analysis Program (IEMCAP): This is a generalized program capable of taking detailed input data describing the physical configuration of an entire system as well as its intrasystem EMC environment and predicting port-to-port and overall EMC levels in relation to military specifications. It is also useful for trade-off and waiver analysis. Its output is a digitized EMC database useful for future system modifications.

(2) General Electromagnetic Model for the Analysis of Complex Systems (GEMACS): This code provides a detailed analysis of the electromagnetic phenomena associated with a complex system. This code uses the Method of Moments (MOM) and Geometrical Theory of Diffraction (GTD) analysis techniques to obtain the electric current distribution over the structure, far-field and near-field radiation patterns, antenna input impedances, and antenna-to-antenna coupling parameters for antennas on structures. Sources of excitation can be antenna input voltages or an incident electromagnetic field from an arbitrary source.

(3) Nonlinear Circuit Analysis Program (NCAP): This computer program allows an engineer to determine the nonlinear transfer functions of an electronic circuit. These transfer functions are calculated using the Volterra series approach. They are directly related to such phenomena as intermodulation, cross modulation, desensitization, gain compression/expansion, spurious responses, etc. The use of a sparse matrix technique enables NCAP to analyze typical circuits with 500 to 600 nodes.

(4) Wire-to-Wire: These prediction models are based on a complete and unified consideration of multiconductor transmission line theory as it applies to the prediction of wire-coupled interference. Of particular interest is the WIRE code which predicts terminal currents induced in a multiconductor transmission line by an incident electromagnetic field.

Further information is available in "Intrasystem Analysis Program (IAP) Code Summaries", J.J. Dobmeier, A.L.S. Drozd, and J.A. Surace, RADC-TR-83-101, May 1983, AD A135664.

PROTECTION AGAINST TRANSIENT CURRENTS (EMP) ON MULTICONDUCTOR TRANSMISSION LINES

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*)Technical University Hamburg-Harburg
Postfach 90 14 03, 2100 Hamburg 90
**)NBC Defense Research and Development Institute
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Electromagnetic interferences penetrating the shield of sensitive electronic devices via cable entries are significantly responsible for reduction of the shielding effectiveness. Therefore, an effective protection of cable entries is necessary. In order to realize an optimum protection by special circuits the shape of the interference pulse as a function of time-particularly the edge steepness - must be known, because the response of protection circuits - consisting of gas arresters and suppressor diodes - is dependent on the edge steepness of the interference pulse.

Starting from the frequency-dependent transfer impedance of a multiconductor cable sheath the propagation of the currents, coupled from the cable sheath into the lines, is computed by means of the transmission line equations in the frequency domain. Concerning the computations an equivalent circuit diagram of the multiconductor transmission line is taken as a basis, which considers not only the inductive and capacitive couplings but also the line losses. Dependent on an arbitrary termination, including match-termination, the computation of the currents at arbitrary points on any line of a multiconductor transmission line is possible. Using the transmission line equations the wave equations for the multiconductor transmission line can be obtained. A decoupling of this differential equation system is realized by means of a special transformation (eigenvalue problem).

Theoretical and experimental results will be presented showing coupling and propagation processes of transient currents (EMP) on multiconductor transmission lines as well as the response of special protection circuits. The applying surge voltages for testing these circuits show edge steepnesses up to 2 kV/µs (lightning) and up to 5 kV/ns (EMP).

HARDNESS MAINTENANCE EXPERIENCES ON EMP PROTECTION EQUIPMENT

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For the past four years, Teledyne Brown Engineering has been developing and documenting a data base of EMP hardening experiences on military systems, facilities, and equipment over their life cycle. Information accumulated to date reveals that numerous costly and time consuming problems in the maintenance of EMP protection equipment have been encountered. Many of these problems have occurred repeatedly during the life cycle of systems and many could have been avoided if management, design, test, maintenance, and operating personnel were knowledgeable of experiences captured on other programs. Since the deployment of future military systems and constructed facilities to support these systems will dictate a hardness requirement, it is essential for project managers and engineers to become knowledgeable of lessons learned, new methods and techniques, and mistakes previously made in hardness programs to avoid making the same mistakes in the future.

This paper describes a documented EMP hardness information data base and presents many EMP related hardness maintenance experiences captured over the life cycle of weapon system facilities, early warning systems, missile systems, and communication systems. Corrective action taken to resolve hardening problems are identified, including their effectiveness. The experiences provided identify deficiences in system documentation and specifications and describe many problems that are maintenance related during construction/installation, verification testing, operation, and field maintenance of EMP protective features. Also, many hardening problems encountered with maintenance of test equipment, instrumentation, and simulators during in-place validation test programs are identified. Cases are noted in which many of the mistakes made previously were repeated on other hardening programs simply because project managers and engineers had access to only limited past experience accumulated on hardened systems. Sources of information being used in the development of the data base include lessons learned, hardness verification test results, maintenance/surveillance data, and hardness assessment reports.

It is felt that forums like NEM must be used to inform the community of the availability of this documented EMP hardness information to assure maximum usage as well as minimize duplication of efforts.

This work was sponsored by the Defense Nuclear Agency and the U.S. Army Ballistic Missile Defense Systems Command.

EMP HARDENING FEATURING INTERACTIVE GRAPHICS AND COMPUTER AIDED DESIGN

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P.O. Box D, Gainesville, VA 22065

ABSTRACT

This paper summarizes recent advances in EMI control methodology and procedures with applications featuring computer interactive graphics and computer aided design. The problem selected for demonstration is electronic system design and retrofit to harden against electromagnetic pulse threats. Live demonstrations will be presented using an IBM Personal Computer display projected on a large viewgraph transparency screen.

EMI control methodology and procedures is a technique which predicts and analyzes electronic equipments to determine their EMI radiated susceptibility to any defined or defaulted electromagnetic environment and how to harden thereto. First, the ambient is defined across the 10kHz-10GHz spectrum from licensed transmitters, lightning strokes, ESD or EMP threats in eleven half-decade bands. Then salient data (sensitivity, noise immunity level, bandwidth, stop-band slope, impedance) are determined for analog and/or logic sources in one equipment talking to similar circuits in another equipment. Other data are also defined, such as I/O cable type, length, geometry, shields, shield grounding and grounding or floating of mother boards and boxes.

The program predicts common-mode coupling into system ground loops and converts this to differential mode at the victims. The program also computes direct radiation coupling of differential mode into I/O cables. The outputs are combined and processed through the victim analog and/or logic responses. Thence the interference-to-noise (I/N) ratios are calculated across the 10kHz-10GHz spectrum. The dominant EMI failure coupling mode is quantitatively identified together with prompters, i.e., what EMI fix candidates are available.

The user then selects one or more fixes from the list (float PCB, float box or equipment, use ground choke, use optical isolator, use fiber optics, isolation transformer, add EMI filter, etc.). The program is then iterated with the changes and the new performance is again shown on screen. This process is repeated until the objective I/N ratio is achieved. Then the entire EMI-fix history is displayed so that all fixes are clearly evident. This allows overall critique so that a more effective cost-benefit solution or the best of several solutions may be chosen.

To fully exercise the above EMI control methodology and procedure, a nuclear electromagnetic pulse of 50kV/m is selected. The IBM PC display is projected on a large screen to facilitate following the action. Thus, this paper is presented by interlacing traditional viewgraph transparencies of topic material with computer projections - all on the same screen.

USE OF FILTER PIN CONNECTORS FOR EMP PROTECTION

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Jerry McCormack
McDonnell Douglas Aircraft Corp., St. Louis, MO 63166

Filter pin (contact) connectors are an interface specified for electromagnetic interference (EMI) protection of certain electronic systems. The F/A-18A aircraft, for example, has extensively used such connectors on many of its electronic systems. Even though not originally specified for EMP protection, the filter pin connectors are expected to significantly alter the EMP energy delivered to the electronic circuitry.

Literature from Bendix shows a typical filter to be roughly equivalent to a conventional low-pass Pi filter. The central filter pin contact is surrounded by a ferrite sleeve, itself surrounded by a barium titanate capacitor. The internal and external gaps and the solder joints at either end form the Pi topology.

Several of the Bendix low-pass filter pins used in the F/A-18A aircraft) were extensively tested for EMP response and the outcome presented in this paper. These tests included CW transfer function measurements into various terminations and high power-narrow pulse damage verification. This effort has been sponsored by the Aircraft EMP Technology Development (ACEMPTD) program.

EMP COUPLING SOURCE HANDBOOK FOR ARMY SYSTEM DEVELOPERS

KENDALL T. LEPOER

US Army Electronics Research
And Development Command
Harry Diamond Laboratories
Adelphi, MD 20783

Harry Diamond Laboratories is developing a high-altitude electromagnetic pulse (HEMP) coupling source handbook for Army tactical system developers. The handbook is intended to provide a user-oriented sourcebook for HEMP coupling data for various types of penetrations commonly seen on Army tactical systems. It will enable a system developer to readily predict worst-case HEMP-induced waveforms on cables and antennas in order to define hardness requirements for interface circuits and subassemblies and to specify required terminal protective devices (TPD's). Conversely, knowing the interface subassembly vulnerability level will assist designers in selecting TPD's, cables and equipment to assure hardness. The handbook will also allow design of injection pulsers for verification and maintenance of the hardness of these items. In effect, the HEMP-induced waveforms in the handbook will constitute a set of unofficial HEMP pin specifications.

The handbook will incorporate a great deal of HEMP coupling data, both analytical and experimental, obtained through the years by HDL in many system-assessment programs. This constitutes a large data base for system coupling that until now was scattered throughout a large number of reports. The handbook will unify the data into a single source. Where appropriate, these data will be supplemented by newly developed information, based on experiments and exercise of HDL's coupling codes. A large present effort is concentrating on producing worst-case cable coupling data by use of the FREFLD code.

The data will be organized in a user-oriented format. In general the data will be grouped by configuration of the coupling source and, for each type of coupling source, will contain the following information:

1. Description of the generic coupling source.
2. Standard threat-level waveform and source impedance for a standard length, height, etc.
3. Series of correction factors to apply the standard waveform to various lengths, heights, etc.

Not all the generic coupling sources will have all this information available when the handbook is first published. Whatever is available at the time will be included, and the handbook will be updated periodically as further or better information becomes available.

The paper will dicuss the development, usage, and format of the handbook. It will also include selected coupling data to be furnished in the handbook.

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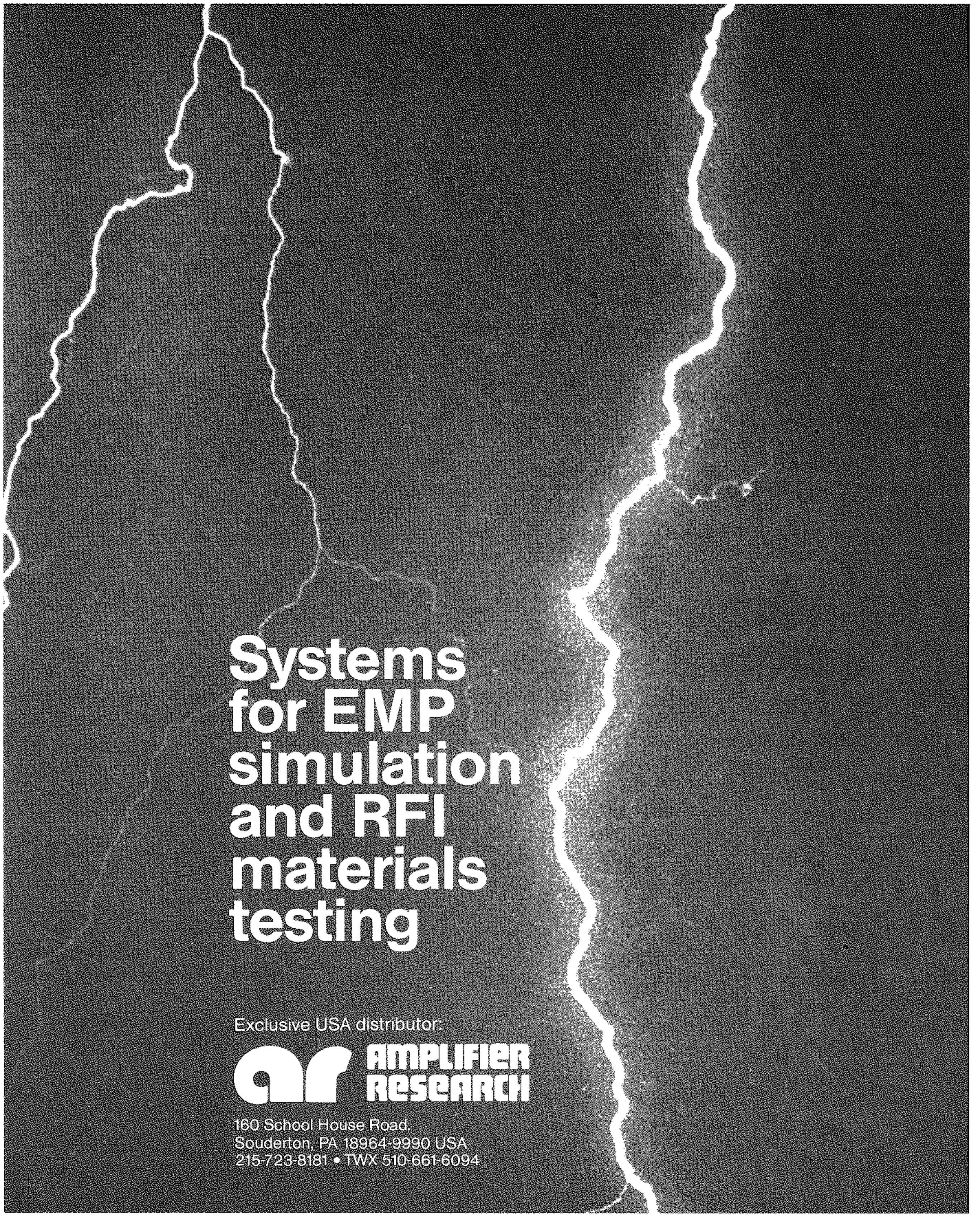
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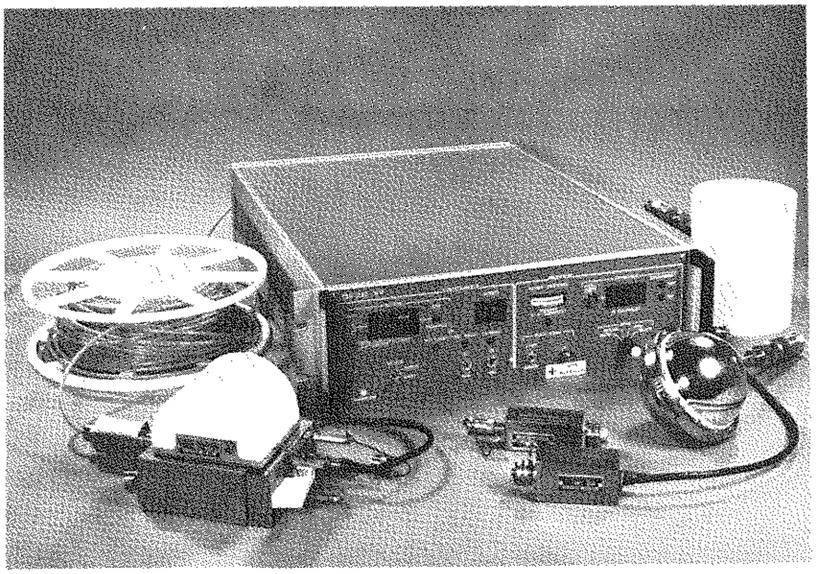

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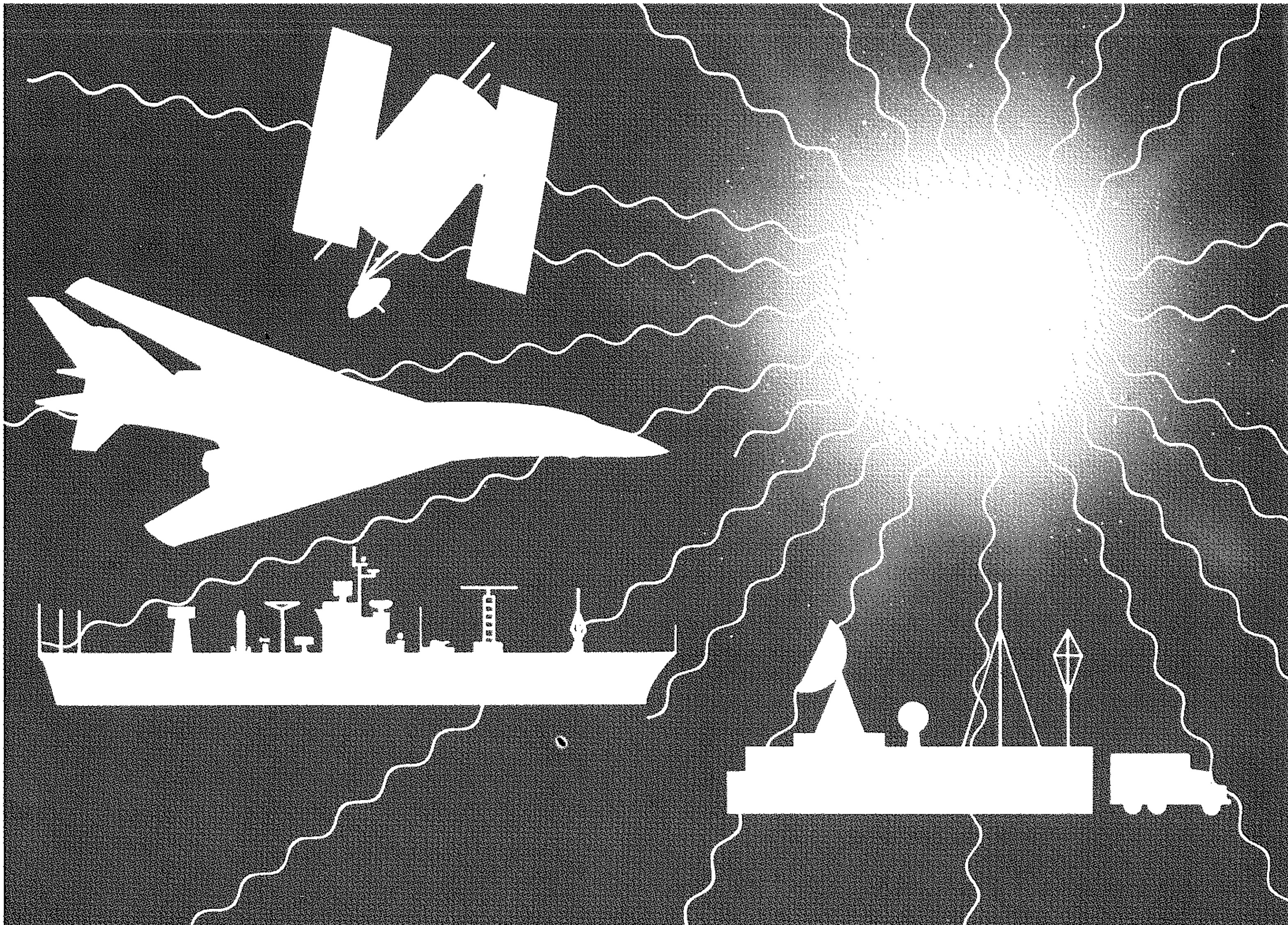

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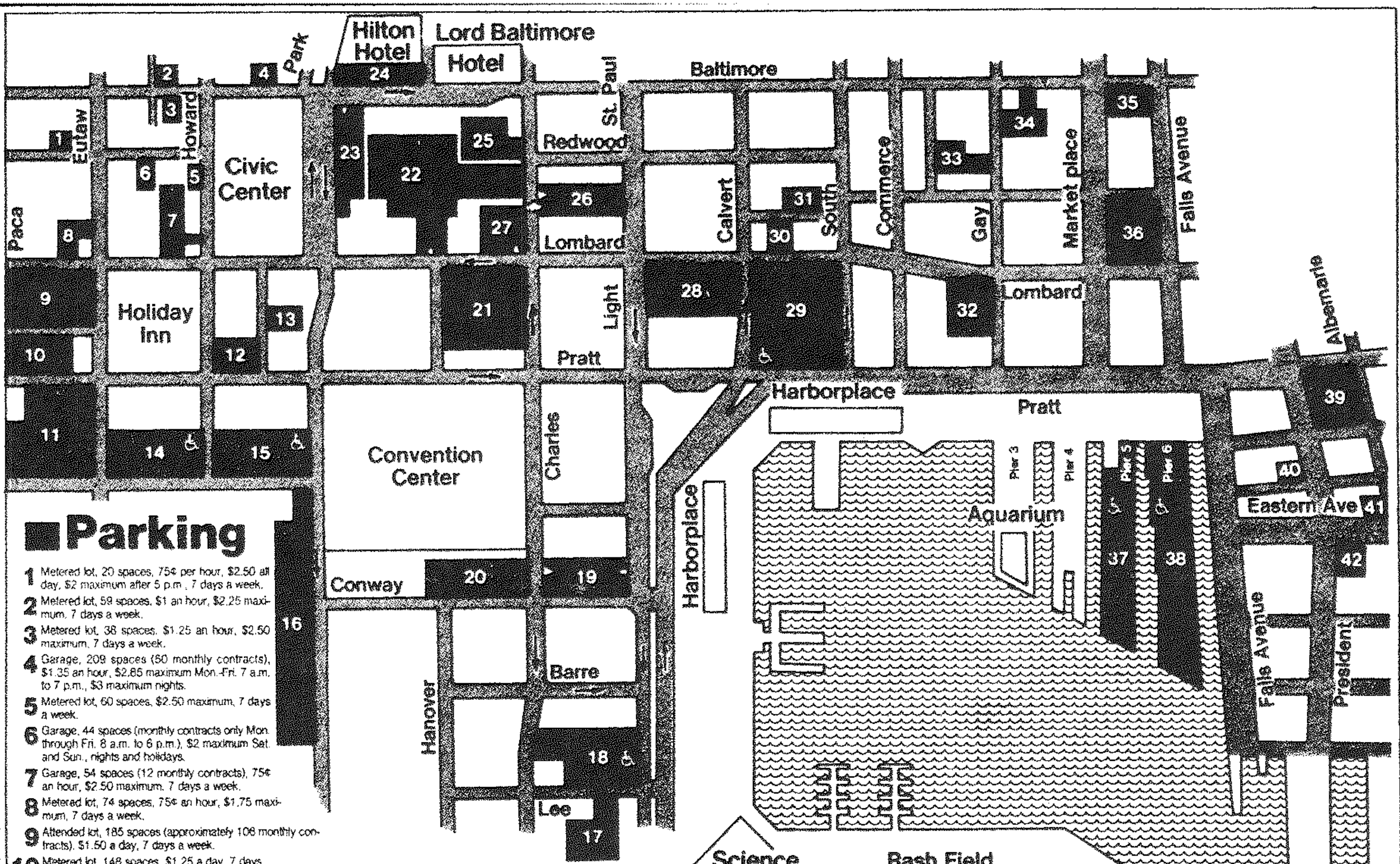

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1 Metered lot, 20 spaces, 75¢ per hour, $2.50 all day, $2 maximum after 5 p.m., 7 days a week.

2 Metered lot, 59 spaces, $1 an hour, $2.25 maximum, 7 days a week.

3 Metered lot, 38 spaces, $1.25 an hour, $2.50 maximum, 7 days a week.

4 Garage, 209 spaces (50 monthly contracts), $1.35 an hour, $2.85 maximum Mon.-Fri. 7 a.m. to 7 p.m., $3 maximum nights.

5 Metered lot, 60 spaces, $2.50 maximum, 7 days a week.

6 Garage, 44 spaces (monthly contracts only Mon. through Fri. 8 a.m. to 6 p.m.), $2 maximum Sat. and Sun., nights and holidays.

7 Garage, 54 spaces (12 monthly contracts), 75¢ an hour, $2.50 maximum, 7 days a week.

8 Metered lot, 74 spaces, 75¢ an hour, $1.75 maximum, 7 days a week.

9 Attended lot, 185 spaces (approximately 106 monthly contracts), $1.50 a day, 7 days a week.

10 Metered lot, 148 spaces, $1.25 a day, 7 days a week.

11 Metered lot, 233 spaces, 5¢ for 20 minutes, $1.50 for 10 hours (10-hour limit in effect 6 a.m. to 6 p.m.).

12 Metered lot, 88 spaces (35 for carpools only), 25¢ an hour, $2.50 for 10 hrs. (10-hour limit), 7 days a week.

13 Metered lot, 53 spaces, 5¢ for 6 minutes, $2 for 4 hours (4-hour limit), 7 days a week.

14 Computer lot, 180 spaces, 25¢ an hour, 7 days a week, handicapped spaces.

15 Computer lot, 180 spaces, 25¢ an hour, 7 days a week, handicapped spaces.

16 Attended lot, 200 spaces, $1 an hour, $2.50 maximum, 7 days a week.

17 Underground garage, 134 spaces (45 monthly contracts), $1 an hour, $5.15 maximum all day, $2.15 maximum 10:30 a.m. to 7:45 p.m., 7 days a week.

18 Metered lot, 258 regular spaces, handicapped spaces, 5¢ for 20 minutes, $1.50 for 10 hours (10-hour limit in effect Mon. through Fri. 6 a.m. to 6 p.m.).

19 Garage, 650 spaces, 75¢ an hour, $3.75 maximum, 6 a.m. to 2 a.m., 7 days a week.

20 Metered lot, 175 spaces, 25¢ for 1 hour 15 minutes, $2 for 10 hours. (10-hour limit 6 a.m. to 6 p.m. Mon-Fri).

21 Underground garage, 460 spaces (400 monthly contracts), $2.75 all day, Mon. to Fri. 7 a.m. to midnight, Sat. 7 a.m. to 6 p.m., closed Sun.

22 Underground garage, 602 spaces (300 monthly contracts), $4 all day, $1.35 maximum nights, Mon. to Sat. 7 a.m. to midnight.

23 Underground garage, 350 spaces (135 monthly contracts), $3.90 all day, Mon. to Fri. 7 a.m. to midnight, Sat. 8 a.m. to noon, closed Sun.

24 Underground garage, 235 spaces, $1.65 an hour, $3.90 all day, 7 days a week.

25 Underground garage, 177 spaces (35 monthly contracts), $1.50 an hour, $4 all day, $4.25 nights, 24 hours Mon. through Sat., closed Sun.

26 Underground garage, 450 spaces (100 monthly contracts), $4 all day, $2 nights and weekends, 24 hours Mon. through Sat., sometimes Sun.

27 Underground garage, 80 spaces, $1.60 an hour, $4 all day, Mon.-Fri. 7 a.m. to 11 p.m., Sat. 8 a.m.-noon.

28 Garage, 656 spaces, $4 all day, $2 nights and Sat., Mon. to Fri. 7 a.m. to 11 p.m., Sat. 7 a.m. to closing.

29 Metered lot, 371 spaces (100 carpools only), 50¢ an hour regular, 25¢ an hour carpools, 4-hour limit on regular meters, 7 days a week, handicapped spaces.

30 Metered lot, 8 spaces, 25¢ for 37 ½ minutes, 2-hour time limit Mon. to Fri. 8 a.m. to 6 p.m.

31 Garage, 150 spaces, $1.50 an hour, $3.75 maximum, Mon. to Fri. 7 a.m. to 7 p.m., closed weekends.

32 Garage, 650 spaces (300 monthly contracts), 75¢ an hour, $3.75 maximum, 6 a.m. to 2 a.m. 7 days a week.

33 Garage, 300 spaces (282 monthly contracts), $1.50 an hour, $3 maximum, Mon. to Fri. 7 a.m. to 7 p.m., closed weekends.

34 Attended lot, 52 spaces (15 monthly contracts), $1 an hour $3.15 max. weekdays 8 a.m. to 6 p.m. and weekends.

35 Metered lot, 110 spaces, 75¢ an hour, $1.50 maximum, 7 days a week.

36 Attended lot, 300 spaces, $1.10 an hour, $1.70 all day, Mon. to Fri. 7 a.m. to 6 p.m.

37 Computer lot, 591 regular spaces, 20 handicapped spaces, 20¢ an hour Mon.-Fri. 8 a.m. to 6 p.m., free nights, weekends.

38 Computer lot, 650 spaces (200 monthly contracts), 20¢ an hour Mon.-Fri. 8 a.m. to 6 p.m., free nights and weekends, handicapped spaces.

39 Metered lot, 58 spaces, 10¢ an hour, 2 ½-hour limit Mon. through Sat. 6 a.m. to 5 p.m.

40 Metered lot, 20 spaces, 10¢ an hour, 2 ½-hour limit Mon. through Sat. 6 a.m. to 5 p.m.

41 Metered lot, $1.25 day or night, 7 days a week.

42 Metered lot, 40 spaces, 10¢ an hour, 2 ½-hour limit Mon. through Sat. 6 a.m. to 5 p.m.

Parking for Handicapped