

AD-A074 900

RIA-79-U517

August 1979

# TECHNICAL LIBRARY

## Electromagnetic Pulse Interaction and Coupling for the Army Multiple Systems Evaluation Program

by Robert F. Gray



**U.S. Army Electronics Research  
and Development Command  
Harry Diamond Laboratories**

Adelphi, MD 20783

Approved for public release; distribution unlimited.

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturers' or trade names does not constitute an official indorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HDL-TR-1896	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Electromagnetic Pulse Interaction and Coupling for the Army Multiple Systems Evaluation Program	5. TYPE OF REPORT & PERIOD COVERED Technical Report	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) Robert F. Gray	8. CONTRACT OR GRANT NUMBER(s) DA: 1W162118AH75	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Harry Diamond Laboratories 2800 Powder Mill Road Adelphi, MD 20783	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Ele: 6.21.18.A	
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Materiel Development & Readiness Command Alexandria, VA 22333	12. REPORT DATE August 1979	
	13. NUMBER OF PAGES 27	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES HDL Project: X755E2, DRCMS Code: 612118.11.H7500 This work was sponsored by the Department of the Army under Project No. 1W162118AH75/A-29, Multiple Systems Evaluation Program.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Coupling analysis                      Multiple Systems Evaluation Program System vulnerability                    MSEP System hardening                        TEMPO EMP ✓                                        NLINE AESOP                                        FREFLD <i>Elect equip</i> <i>Unit number</i>		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The level of dependence on interaction and coupling analysis for determining Army system vulnerability has increased proportionately with advances in the technical capability and the applicability of the analysis. Early system analysis programs relied heavily on system test data for inputs to damage analysis codes. Interaction and coupling analysis during the Pershing and Lance Missile System tests was limited to field definition		

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED  
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

## 20. Abstract (Cont'd)

for the purpose of scaling the field test data and to investigations into the response of some basic problems, such as a vertical whip antenna and a two-wire line over an infinitely conducting ground plane.

Recent advances in the interaction and coupling areas under Army and Defense Nuclear Agency funded programs have made it possible for analytical response calculations to have a more direct role in the vulnerability assessments of Army systems. Presently, the Harry Diamond Laboratories is determining the vulnerability of 29 multichannel communications systems under the Army's Multiple Systems Evaluation Program (MSEP). Field testing of these systems has been required only for validation of analytical coupling models and circuit code models.

Three main computer codes have been applied to the coupling problems analyzed in the MSEP. These codes are "TEMPO," which contains up-to-date models of a variety of standard antennas along with a semiempirical technique for characterizing the response of more complex antennas; "NLINE," which treats multiconductor transmission lines; and "FREFLD," which is a transmission-line solution for the response of a coaxial cable. Typically, each of these codes depends on a specialized test or analysis technique to determine input parameters for the specific antenna or cable system under consideration.

This paper contains an overview of the three codes, showing the applications of the codes and techniques to particular system problems, along with the levels of confidence obtained.

## FOREWORD

This paper presents an outline of the development of analytical tools and field testing for the analysis of nuclear electromagnetic pulse (EMP) interaction and coupling into tactical Army systems. A historical background is portrayed of the efforts of the Electromagnetic Effects Laboratory of the Harry Diamond Laboratories (previously a laboratory of the U.S. Army Mobility Equipment Research and Development Center). The advances both directly and through the guidance of technical contractors are documented in the references. This paper then brings the reader up to date on the current state of analysis in EMP interaction and coupling of tactical Army systems.

CONTENTS

	<u>Page</u>
1. INTRODUCTION . . . . .	7
2. PRIOR SYSTEMS . . . . .	7
3. PRESENT SYSTEMS . . . . .	8
4. PRESENT ANALYSIS . . . . .	10
5. VALIDATION PROCESS . . . . .	13
6. CONCLUSIONS AND RECOMMENDATIONS . . . . .	19
LITERATURE CITED . . . . .	20
DISTRIBUTION . . . . .	23

FIGURES

1 Lance Missile System . . . . .	7
2 Typical Army Communication Equipment . . . . .	9
3 Manpack Portable Radio Set, AN/PRC-77 (30 to 76 MHz) . . . . .	10
4 Generic Assessment Method for a Priori Hardening Systems in Vulnerability and Hardness Assessment . . . . .	11
5 Preferred Prediction Method for Applying Interaction and Coupling Codes to Systems . . . . .	12
6 Multiexponential Curve Fit Comparison of Radial Magnetic Field at 0, 200, and 0.5 m from Army EMP Simulator Operation (AESOP) Simulator . . . . .	13
7 Validation Result for Simple System: 100-m Field Wire on Ground with System Termination on One End . . . . .	14
8 Configuration for Radio Set AN/TRC-145 Field Test . . . . .	15
9 External Cable Current at Test Unit for Radio Set AN/TRC-145 Pulse Code Modulation Cable at 4.6 m with ac Generator . . . . .	16
10 Internal Current on Shields of Coaxial Cable Pair for Radio Set AN/TRC-145 Pulse Code Modulation Cable at 4.6 m with ac Generator . . . . .	17
11 Current on Shields of Coaxial Cable Pair for Radio Set AN/TRC- 145 Pulse Code Modulation Cable at 4.6 m without ac Generator . . . . .	17
12 Pulse Code Modulation Cable Field Test Response . . . . .	19

## 1. INTRODUCTION

Interaction and coupling analysis has had an increasing role in recent Army systems electromagnetic pulse (EMP) vulnerability assessments. The level of reliance on predictive coupling tools has changed from simply providing confidence in system level tests to using, in all current Army assessments, predicted responses that rely on system level test comparisons for confidence. This fact may best be pointed out by reviewing early Army systems, their coupling problems, and the interaction and coupling work performed during these programs and comparing these with what is presently being accomplished under the Army's Multiple Systems Evaluation Program (MSEP).

## 2. PRIOR SYSTEMS

In the late 1960's and early 1970's, the Pershing Missile System and the Lance Missile System (fig. 1) were extensively tested<sup>1-3,\*</sup> and analyzed<sup>4,5</sup> for vulnerability to the high-altitude EMP threat. Although Pershing is much more complex than Lance, the coupling problems presented by the two missile systems were similar. Also, essentially the same testing and analysis philosophy was used in each assessment.

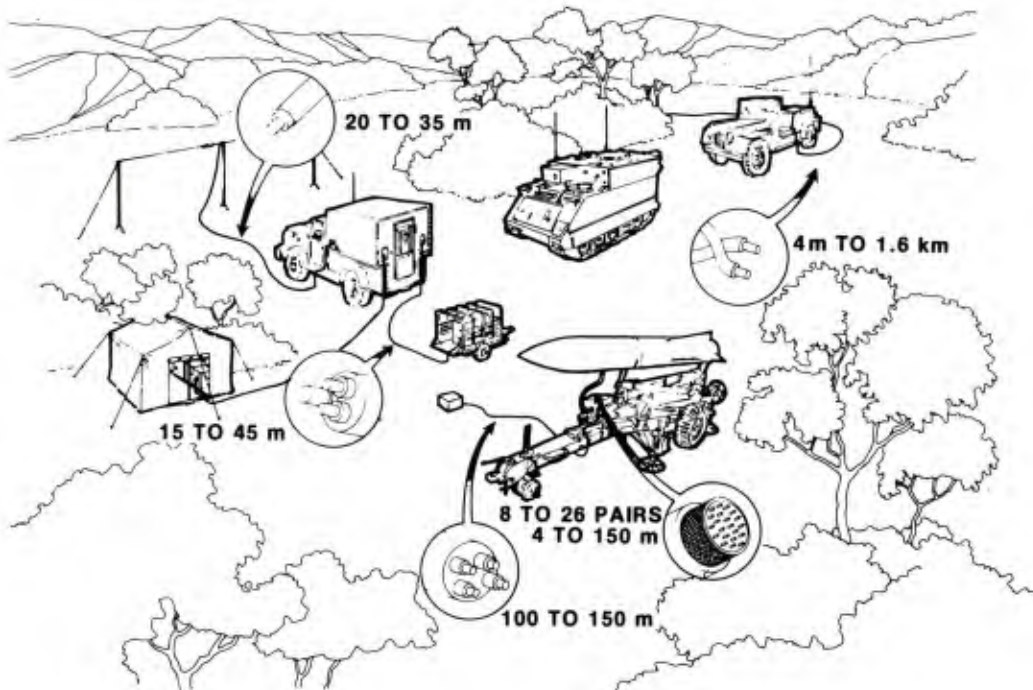


Figure 1. Lance Missile System.

*\*Numbers refer to entries in the Literature Cited section.*

Various types of major coupling problems in these systems also are shown in figure 1. A variety of multiconductor cables appears in these systems. The multiconductor cables that had external shields ranged in size from 8 to 26 pairs of conductors and in length from 4 to 150 m. These cables are used to interconnect units mounted on the same chassis or other nearby vehicles and equipment. The unshielded multiconductor cables were typically used for power distribution and consisted of three or four conductors varying in length from 15 to 150 m.

The communication equipment associated with these systems employed simple whip antennas mounted on the signal shelters or vehicles and dipole antennas with coaxial feeds. The only land line used for communication is the WD-1/TT twisted pair of field wires which, for these systems, was limited to lengths of run up to 1.6 km. The twisted pair of field wires is the most commonly used cable in the Lance, and it is found in nearly all Army systems.

The vulnerability assessment of these systems relied heavily on extensive simulator testing to determine the response characteristics of the cables and the antennas. There were some initial attempts to modeling the coupling to single- and two-wire lines<sup>6-9</sup> and to some simple antennas<sup>10</sup> such as whips. Although these solutions were not used in the damage assessments of the systems, they added confidence to the measured system data that were used as input to the circuit analysis codes.<sup>11,12</sup>

Another major analytical effort during this period was defining the field output of the various simulators<sup>13-18</sup> used and comparing them with the output expected from a real threat.<sup>19</sup> In this way, the necessary scale factors for the system response data were determined.

In addition to the system testing being conducted at the time, many experiments were conducted on various simple coupling problems. These data proved useful in later code validation. Three computer codes that are being applied in present system studies were in their initial development stages during this period under funds provided by both the Army and the Defense Nuclear Agency. These codes are TEMPO, NLINE, and FREFLD.

### 3. PRESENT SYSTEMS

In recent years, the Army has been concentrating<sup>20-24</sup> on the communication equipment employed from the forward edge of the battle area back to the corps level (fig. 2). Some of the coupling problems associated with these systems are very similar to those encountered in the earlier missile systems. Essentially, the same power cabling and coaxial cable feeds for antennas are used in these systems along with the standard twisted pair of field wires.

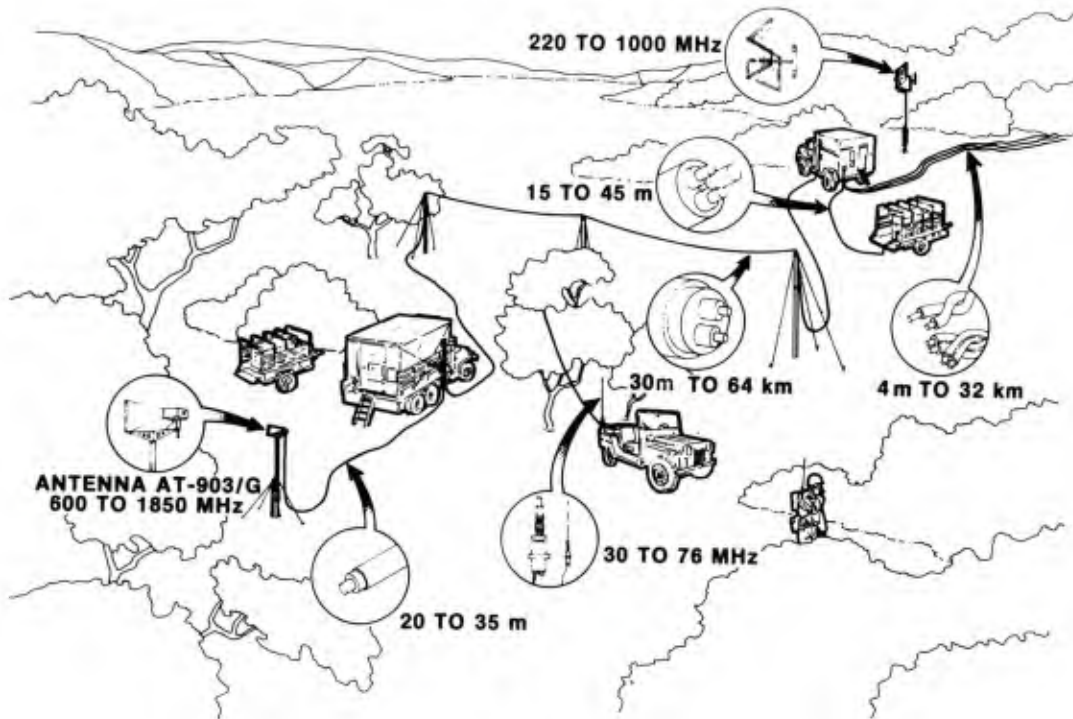


Figure 2. Typical Army communication equipment.

However, cable lengths and system terminations are more varied now. In addition to the standard twisted pair of field wires, a twisted four-wire telephone cable used with some of this equipment may also have lengths of runs up to 32 km.

Many of these systems have multichannel transmission capabilities either by radio link or through land lines. These land lines may be up to 64 km without a manned repeater, and the cabling may be deployed from ground level to a height of about 5 m. Unattended in-line repeaters are required every 1.6 km when long lengths of cable are used. This land line or pulse code modulation (PCM) cable consists of two coaxial cables, one for transmitting and one for receiving, which are twisted and covered by an overall braided shield.

Also, various antennas are used by this equipment. Some of the single-channel radios use a jeep-mounted center feed whip antenna, which has a preselector at the base of the antenna. The multichannel equipment uses more complex antennas, such as the horn antenna with a coaxial cable feed, which allows significant coupling to the system, and the dipole antenna with a corner reflector, which may be used with

either vertically or horizontally polarized signals. The manpack portable AN/PRC-77 Radio Set (fig. 3) is probably the most common communication equipment in the Army. The AN/PRC-77 is a VHF-FM single channel radio that uses a variety of antennas ranging from a simple whip and a long-wire antenna to the fixed-site log-periodic unit.

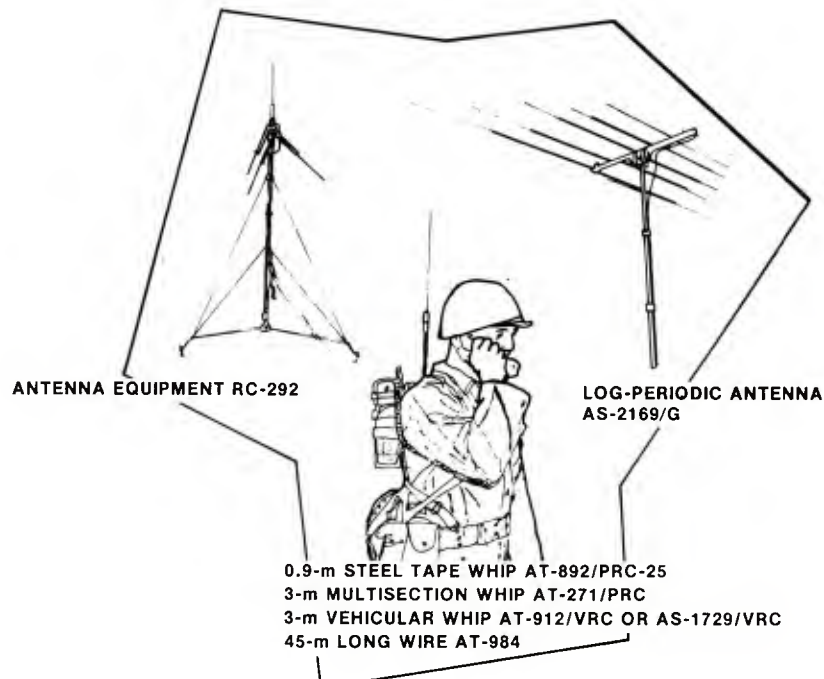


Figure 3. Manpack Portable Radio Set, AN/PRC-77 (30 to 76 MHz).

#### 4. PRESENT ANALYSIS

Unlike the missile system assessments, the vulnerability assessments of this equipment have had a good balance between the experimental testing of the equipment with simulators and the use of analytical tools to determine the coupling response of the systems. Under the MSEP, a system vulnerability assessment has been developed that allows the approach taken to be tailored to meet the problems presented by the system under study: the Generic Assessment Method for a Priori Hardening Systems (GAMPHS) (fig. 4). The GAMPHS incorporates an up-to-date test data analysis based on the early assessments of Lance and Pershing along with an analytical technique for determining the responses of important coupling problems.

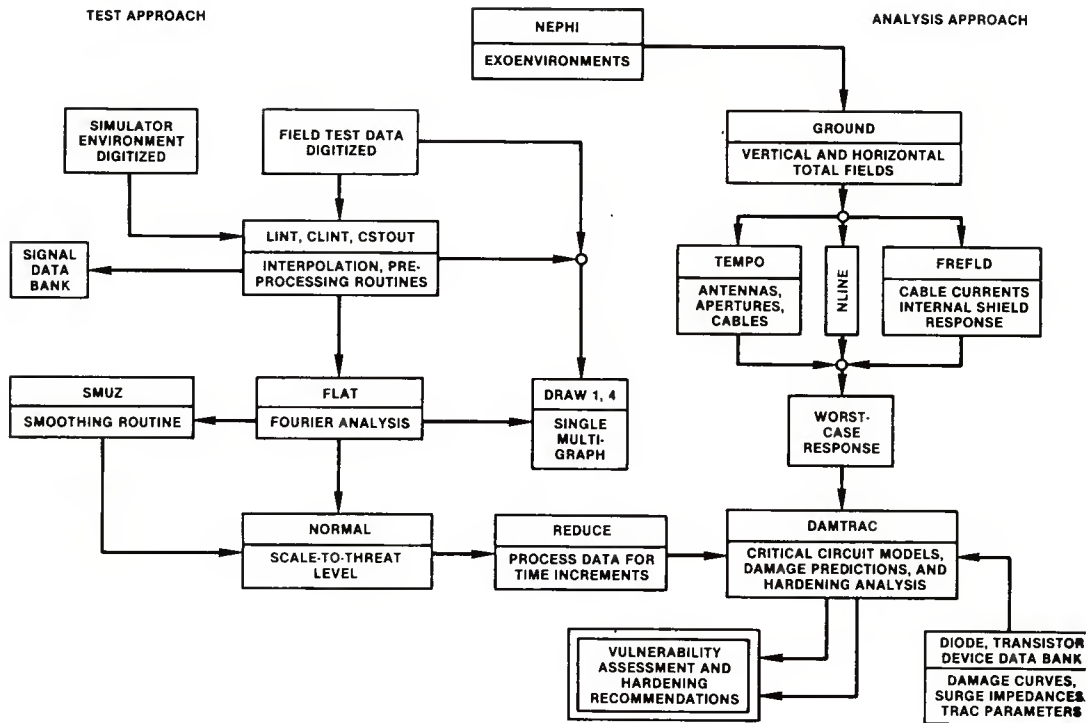


Figure 4. Generic Assessment Method for a Priori Hardening Systems in vulnerability and hardness assessment.

Three main computer codes have been applied to the coupling problems identified for these systems:

TEMPO<sup>25</sup> a compilation of analytical solutions for a variety of antennas plus a semiempirical technique of treating more complex antennas.

NLINE<sup>26</sup> a transmission line solution for EMP coupling with a lossless multiconductor transmission line located aboveground or in free space. This code can handle up to 11 conductors.

FREFLD<sup>27</sup> a transmission line solution for the external and internal responses of a coaxially shielded cable due to an arbitrarily oriented field.

Each of these codes is applied to a specific system coupling problem (fig. 5). The problem definition stage involves an investigation of the system and its various operational modes to define possible prime penetrations. Decisions are made in this stage as to what simulator

testing should be done on the system and what kind of analytical model should be used to treat each problem area. Each of these models requires a number of input parameters, both physical, such as cable length and height, and electrical, such as antenna impedance or shield transfer function. The determination of these electrical parameters typically involves the use of specialized test or analysis technique such as the Continuous Wave Test Facility<sup>28</sup> located at the Harry Diamond Laboratories Woodbridge Research Facility, which is used to determine the transfer function of complex antennas.

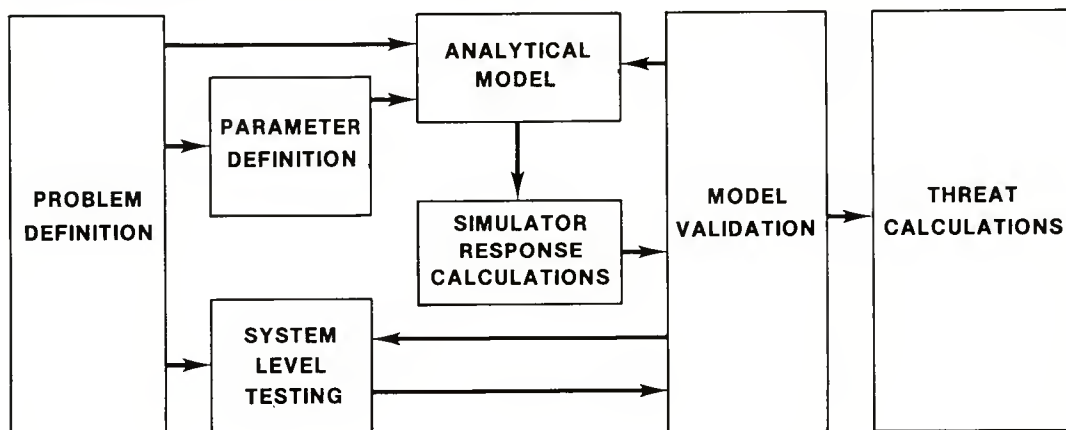


Figure 5. Preferred prediction method for applying interaction and coupling codes to systems.

Once the necessary parameters are known and the specific conditions of the system level test are decided, a set of simulator response calculations is made, normally prior to system testing. A multiexponential curve fit of the simulator output is used in making the correlation calculations. An example of the accuracy obtainable with this type of curve fit is shown in figure 6 in both time and frequency domains. This type of field definition has the advantage of being easy to incorporate into analytical solutions working in either the time or the frequency domain, and it is accurate enough to allow good correlation of results.

The field test measurements and the simulator response calculations are then compared to determine the relative validity of the analytical model. Figure 5 shows the feedback from the validation stage to both the analytical model for modification of parameters, etc., and the field test area to allow for additional test conditions or for retesting to ensure accuracy.

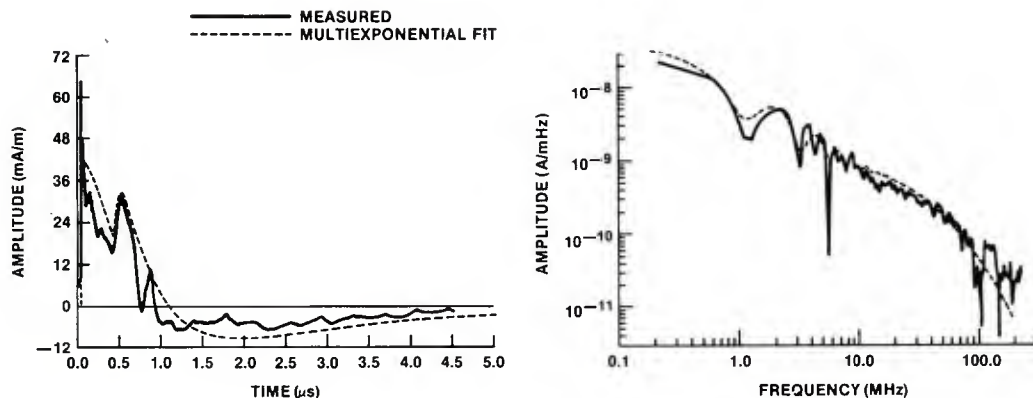


Figure 6. Multiexponential curve fit comparison of radial magnetic field at 0, 200, and 0.5 m from Army EMP Simulator Operation (AESOP) simulator.

Threat-level calculations are not made until the comparison between the measured and calculated responses is satisfactory. At times, this desired level of confidence or validity is reached only after several iterations through the calculation, measurement, and validation stages. In performing these cyclic comparisons, it is important to validate many system configurations to ensure that the model is not being tailored to satisfy only one system and simulator interaction condition. If this is not done, the model may not give the best possible representation of the system for all of its obtainable configurations. Once the validity of the calculational technique has been established, then threat levels are calculated for different field illumination and system configurations to determine if a worst-case response condition exists. These worst-case response calculations are then used in the system vulnerability analysis.

## 5. VALIDATION PROCESS

To demonstrate the levels of confidence obtainable with this preferred prediction method of applying interaction and coupling codes to systems and also to demonstrate some of the problems in its application, the results of two validation efforts are presented here. For continuity, both examples deal with the responses of a cable connected to a system. The same types of results are possible for antennas.

The validation results for the first example, a simple one, are for the response of a 100-m length of field wire connected to a system via filters at the wire termination. A pretest calculation was made for the bulk or common mode current on the field wires by using only the known physical and electrical parameters of the cable and the system-to-earth termination. This pretest calculation and the measured response are given in figure 7. The correlation between the two responses is very good, and no refinement of the analytical model was necessary. The differential voltage response at the system is a much more difficult problem, and therefore its pretest calculated response did not fare nearly so well when compared with the measured response as did the bulk current calculations.

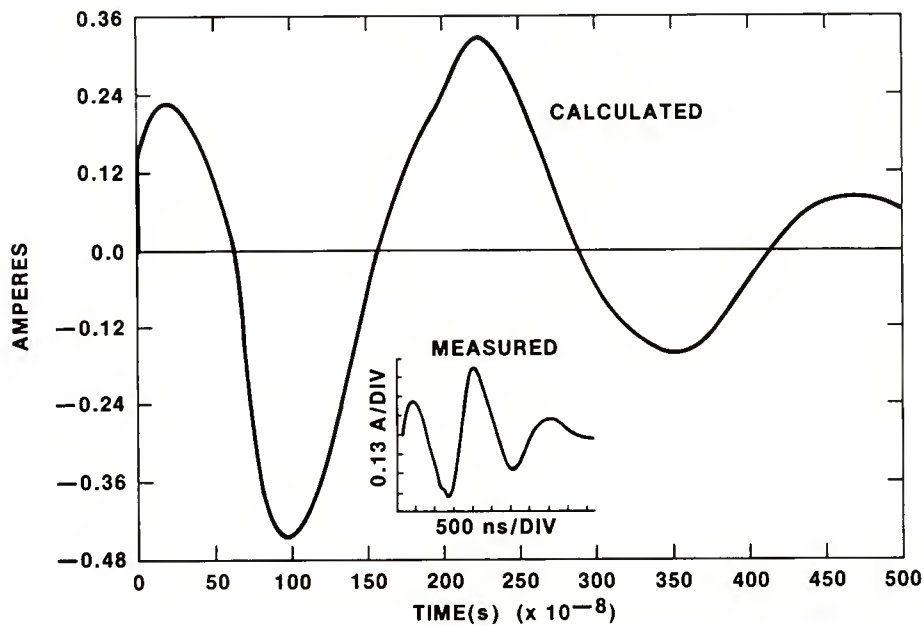


Figure 7. Validation result for simple system: 100-m field wire on ground with system termination on one end.

The validation results for the second example reflect a much more complex system employing the PCM cable (sect. 3) for the multichannel communication equipment AN/TRC-145 Radio Set (fig. 8). The Army EMP Simulator Operations (AESOP) simulator used during this test provided a wave shape corresponding to a horizontally polarized radiating dipole antenna. The AN/TRC-145 was tested 200 m from the AESOP on its center line. The AN/TRC-145 was connected to a remote unit by a 433-m length of PCM cable installed at a height of 4.6 m aboveground. Several other

cables connected the AN/TRC-145 to the test unit (fig. 8), and an ac generator with its ground rod was connected to each unit. All of the following response calculations and measurements were for the unit closest to the AESOP.

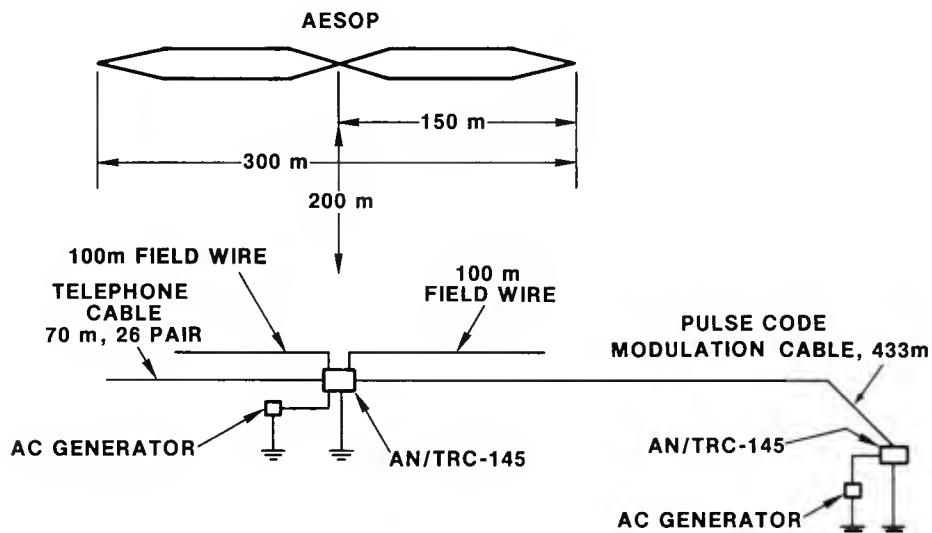


Figure 8. Configuration for Radio Set AN/TRC-145 field test.

The illumination of the PCM cable is far from planar. The peak field, the wave shape, the incidence angle, and the angle of orientation of the cable with respect to the horizontal electric field are functions of the position along the cable. Although the code applied to this problem can handle arbitrary orientations of the cable in the incident field, the field is assumed to be planar and of constant peak value and wave shape along the cable. Therefore, the pretest calculations for this problem consisted of a series of calculations for different angles of cable rotation in the field and of different field waveforms. The first cycle through the validation stage showed that several of the calculations would represent certain portions of the measured response. One calculation agreed well with the measured peak current, but agreed poorly with other characteristics of the measured data such as the time of arrival of the first reflection from the far unit or the late-time ring down. However, one of the other calculations agreed well with ring down, but agreed poorly with the peak amplitude.

Therefore, for the second validation example, the model was adjusted to obtain an average calculation, which was not necessarily the most accurate for any one item or portion of the response, but which best represented the overall measured system response. For the final validation results, figure 9 shows the external current response at the

test unit, and figure 10 shows the internal current on both of the coaxial cable shields. The general characteristics of the two measurements are close to those of the calculated responses. However, the specifics such as peak amplitudes, which differ by factors of two or three at some points, are not nearly so accurate as were obtained for the first validation example.

Since these calculations required several iterations through the validation stage, some assurance was needed that the resulting model could be applied to conditions other than those used for the field test. Therefore, an additional set of field measurements was requested that used the same cable layout (which could not easily be reconfigured) due to the problems involved in accurately installing the cable for test. But the system-to-earth impedance was altered by removing the ac generators and, therefore, their grounds from the system. This terminating impedance change was accounted for in the analytical model, and the resulting comparison for the current on the inner coaxial cable shields is given in figure 11. In comparing the responses without the ac generator grounds to those in figure 10 with the grounds, one should note that both the calculated and the measured responses exhibit much greater damping of the late-time response. Although this new comparison does not offer definite proof that the model will retain the same level of confidence for all other configurations, it does contribute significantly to the overall confidence in the analytical representation of the system.

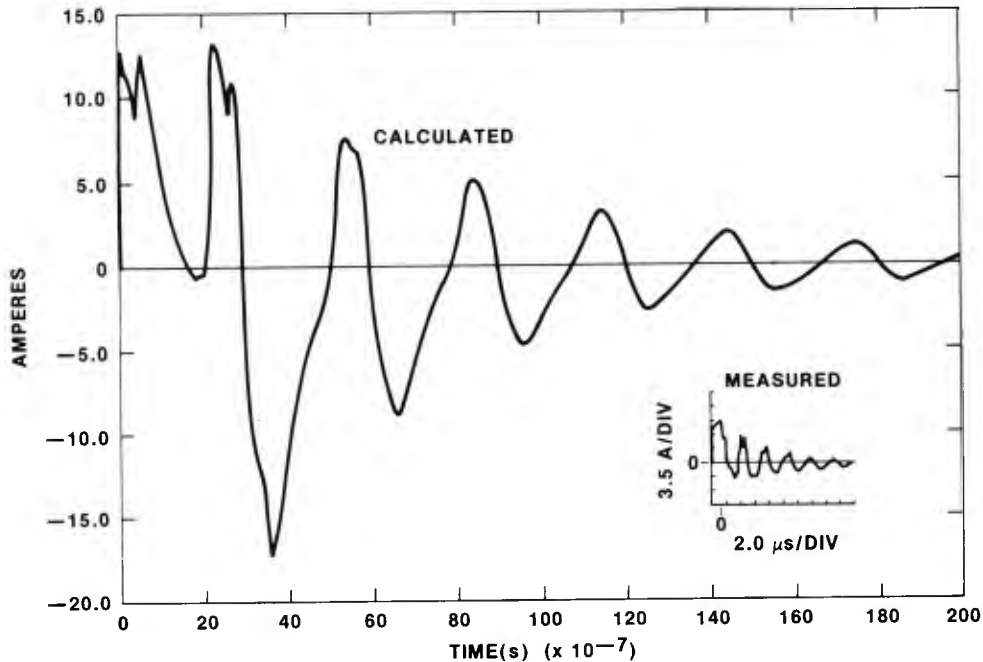


Figure 9. External cable current at test unit for Radio Set AN/TRC-145 pulse code modulation cable at 4.6 m with ac generator.

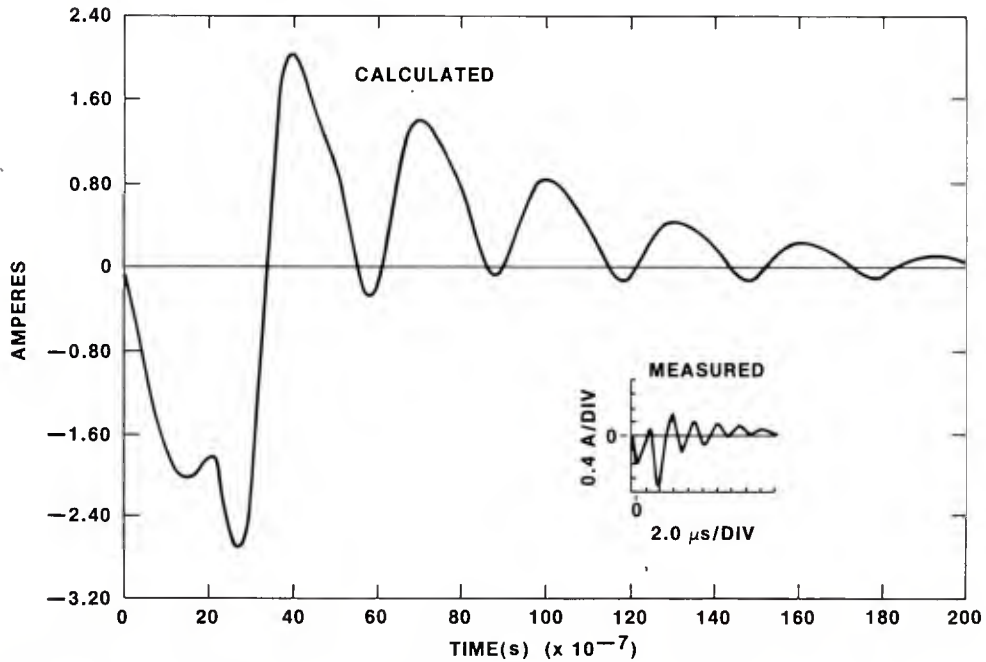


Figure 10. Internal current on shields of coaxial cable pair for Radio Set AN/TRC-145 pulse code modulation cable at 4.6 m with ac generator.

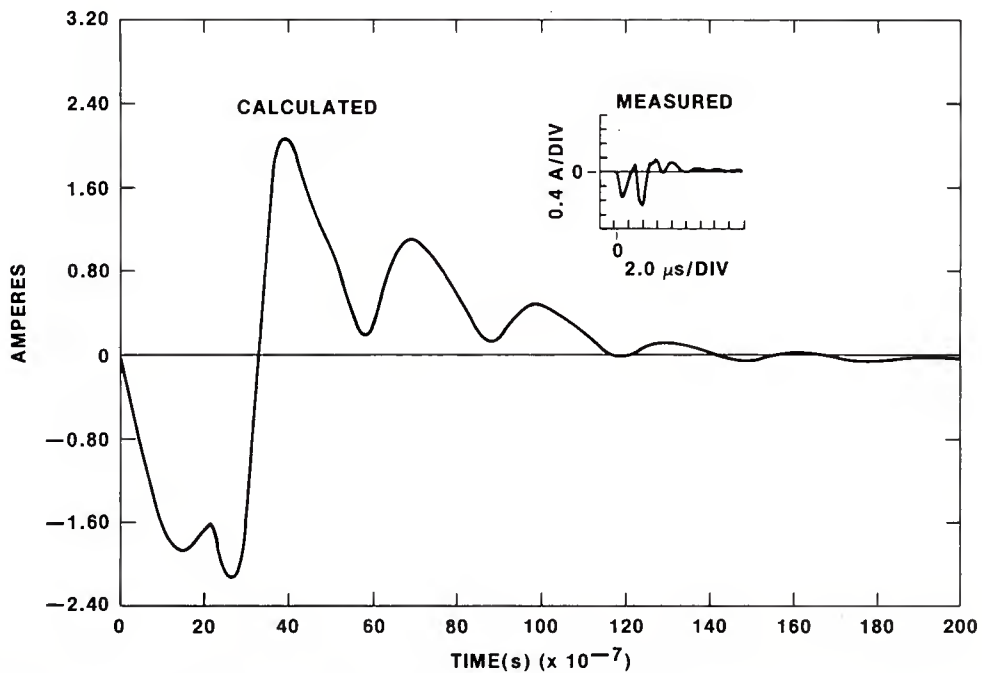


Figure 11. Current on shields of coaxial cable pair for Radio Set AN/TRC-145 pulse code modulation cable at 4.6 m without ac generator.

The validation comparisons given so far for the system with the PCM cable have been limited to the exterior current and the coupling to the shields of the two coaxial cables. Since a vulnerability analysis requires the voltage or current response of each coaxial cable, not just the current on its shield, an additional analytical model for this response had to be developed and validated.

Detailed modeling of the coupling through both the external shield and one of the internal coaxial shields was not possible with the available analytical tools since code FREFLD treats only singly shielded cables. However, through shielding effectiveness testing conducted on the PCM cable, it was found that the coupling through the shield of the internal coaxial cable was essentially a resistive effect over the range of frequencies of interest. Therefore, the shield transfer impedance used for calculating the response of coaxial cables was the parallel resistance of the external shield and the two coaxial cable shields. Figure 12 compares the calculated voltage response and that measured during the system field test.

The general wave shapes agree well, but the amplitude differs by about a factor of five. At first glance, this difference may seem poor. But if one considers the approximations that had to be made in the model and the relatively poor simulation that was possible, then it seems reasonable that the calculated responses should tend to be greater.

Also, the fact that the analytical model produces a larger response than may actually occur in the event of an EMP merely makes the system assessment more conservative. The validation of the analytical model with the system level test ensures that the interaction and coupling estimates are not so conservative that protecting the system to the predicted signal levels is not feasible or cost effective.

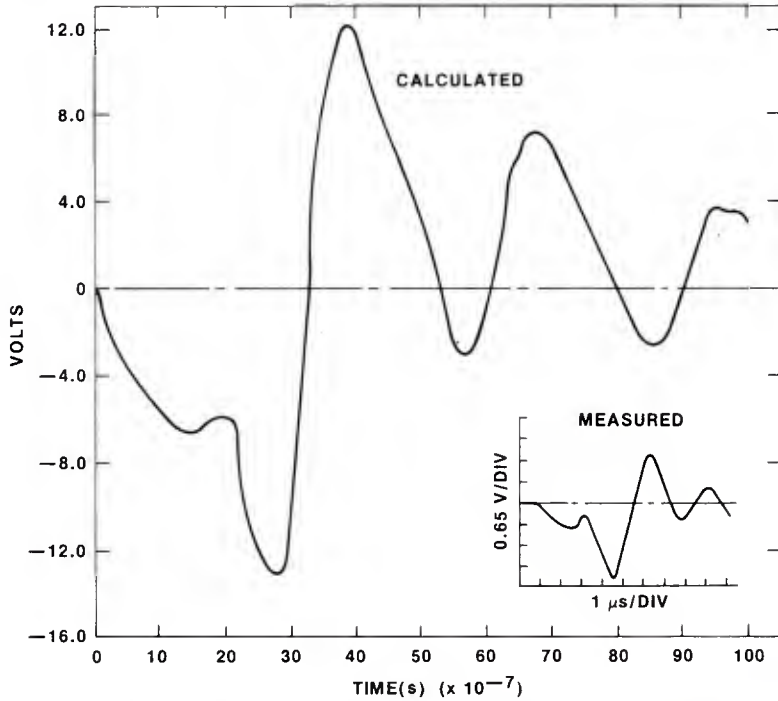


Figure 12. Pulse code modulation cable field test response.

## 6. CONCLUSIONS AND RECOMMENDATIONS

This preferred prediction method for applying interaction and coupling codes to systems allows greater accuracy in system vulnerability assessments than do programs based solely on analytical or experimental methods of handling the primary interaction and coupling problems. Complex systems similar to the ones in the MSEP can have too many uncertainties to be handled easily by a purely analytical method. These uncertainties might result in such conservative assessments that the protection requirements would be impossible to meet. Moreover, purely experimental assessments involving worst-case simulation with existing simulators are possible for only a few systems. It is important to obtain a good balance between simulation testing of systems and interaction and coupling analysis.

LITERATURE CITED

- (1) Donald Dinger, R. J. Bostak, J. D. Dando, and W. Haas, White Paper on Pershing 1a Special Test Program (U), 3rd Ed., U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA (10 June 1968). (SECRET)
- (2) Jere D. Dando, Pershing Special Test Program Phase I, Final Report, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA (March 1969).
- (3) Jere D. Dando, Guidelines for Pershing 1a Special Test Program (STP) Phase II, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA (13 June 1969).
- (4) Jere D. Dando, Pershing Special Test Program Phase II, Final Report (U), Harry Diamond Laboratories (May 1973). (TOP SECRET FORMERLY RESTRICTED DATA)
- (5) Robert A. Pfeffer and Heinz G. Mueller, LANCE Missile System EMP Test Program (U), Harry Diamond Laboratories HDL-TR-1756 (November 1976). (SECRET RESTRICTED DATA)
- (6) Eugene J. Putzer, Ken Schwartz, and Glenn L. Brown, The Coupling of Transient Fields into Cables and Transmission Lines above a Conducting Earth, Final Report, American Nucleonics Corp., Anaheim, CA, Contract DA44-009-AMC-1463(T) (August 1970).
- (7) Eugene J. Putzer, Theory of the Driven Two-Wire Transmission Line, Final Report, American Nucleonics Corp., Anaheim, CA, Contract DA44-009-AMC-1463(T) (February 1969).
- (8) Carrell D. Whitescarver, Transient Electromagnetic Field Coupling with Two Wire Uniform Transmission Lines, Ph.D. Dissertation, University of Florida (1969).
- (9) Werner Stark, An Analytical and Experimental Investigation of Cable Responses to a Pulsed Electromagnetic Field, Harry Diamond Laboratories HDL-TR-1618 (December 1972).
- (10) Peter P. Toullos et al, Effects of EMP Environment on Military Systems Final Report, I, ITT Research Institute, Chicago, IL, Contract DAAK02-68-C-0377 (February 1969).

LITERATURE CITED (Cont'd)

- (11) L. D. Milliman et al, CIRCUS--A Digital Computer Program for Transient Analysis of Electronic Circuits, The Boeing Co., Seattle, WA, Contract DA-49-186-AMC-346(X) (January 1967).
- (12) E. D. Johnson et al, Transient Radiation Analysis by Computer Program (TRAC), North American Rockwell Corp., Anaheim, CA, Contract DAAG39-68-C-0041 (June 1968).
- (13) Janis Klebers, A Study of the Long Wire Antenna Environment Characteristics (U), U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA (21 October 1968). (CONFIDENTIAL)
- (14) E. F. Vance, Field Mapping and Data Analysis for a Long Wire Antenna (U), Stanford Research Institute, Menlo Park, CA, Technical Report 1, Subcontract BDM-S1-67-C-66, Prime contract DAAK-02-67C-0168 (January 1969). (SECRET)
- (15) Janis Klebers and Stanley Bukalski, A Theoretical and Experimental Evaluation of a Biconic Antenna Nuclear EMP Simulator (U), Proceedings of Army Science Conference, West Point, NY (June 1970). (SECRET)
- (16) Richard L. Monroe, Approximate Step Function Response of a Horizontally Polarized Electromagnetic Wave Reflected at an Imperfectly Conducting Surface, J. Appl. Phys., 41 (November 1970), 4820-4822.
- (17) Richard L. Monroe, Approximate Step Function Response of a Vertically Polarized Electromagnetic Plane Wave Reflected at an Imperfectly Conducting Surface, J. Appl. Phys., 40 (August 1969), 3526-3531.
- (18) Janis Klebers, Time Domain Analysis of the Electromagnetic Field in the Presence of a Finitely Conducting Surface, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, VA (29 January 1969).
- (19) Nuclear Survivability Criteria for Army Tactical Equipment (U), Office of the Chief of Research, Development and Acquisition, U.S. Army Nuclear Agency ACN 04257 (1 August 1974). (CONFIDENTIAL RESTRICTED DATA)

LITERATURE CITED (Cont'd)

- (20) George Gornak et al, EMP Assessment for Army Tactical Communication Systems: Transmission Systems Series No. 1: Radio Terminal Set AN/TRC-145 (U), Harry Diamond Laboratories HDL-TR-1746 (February 1976). (SECRET RESTRICTED DATA)
- (21) George Baker and Werner Stark, EMP Vulnerability Analysis of Radio Sets AN/PRC-77, AN/VRC-64, and AN/GRC-160 (U), Harry Diamond Laboratories HDL-TR-1747 (February 1976). (SECRET RESTRICTED DATA)
- (22) Ting H. Mak and Leslie Basner, EMP Assessment for Army Tactical Communications Systems: Transmission Systems Series No. 2: Radio Terminal Set AN/TRC-117 (U), Harry Diamond Laboratories HDL-TR-1769 (October 1976). (SECRET RESTRICTED DATA)
- (23) Michael J. Vrabel, EMP Assessment for Army Tactical Communications Systems: Transmission Systems Series No. 3: Radio Terminal Sets AN/TRC-112 and AN/TRC-121 (U), Harry Diamond Laboratories HDL-TR-1807 (May 1977). (SECRET RESTRICTED DATA)
- (24) Ting H. Mak, EMP Assessment for Army Tactical Communications Systems: Transmission Systems Series No. 4: Radio Terminal Set AN/TRC-138 (U), Harry Diamond Laboratories HDL-TR-1809 (June 1977). (SECRET RESTRICTED DATA)
- (25) Werner J. Stark and David A. Clark, User's Manual for the Interaction and Coupling Code TEMPO (U), Interim Report, Harry Diamond Laboratories (May 1977).
- (26) Janis Klebers, User's Manual for the NLINE Multiconductor Transmission Line Computer Code, Harry Diamond Laboratories HDL-TR-1803 (May 1977).
- (27) Robert F. Gray, Nuclear Electromagnetic Pulse Simulation by Point Source Injection Techniques for Shielded and Unshielded Penetrations, Harry Diamond Laboratories HDL-TR-1737 (December 1975).
- (28) Werner J. Stark, Transient Response of a Log-Periodic Antenna Based on Broad-Band Continuous-Wave Measurements, Harry Diamond Laboratories HDL-TR-1792 (April 1977).

DISTRIBUTION

DEFENSE DOCUMENTATION CENTER  
CAMERON STATION, BUILDING 5  
ALEXANDRIA, VA 22314  
ATTN DDC-TCA (12 COPIES)

COMMANDER  
US ARMY RSCH & STD GP (EUR)  
FPO NEW YORK 09510  
ATTN LTC JAMES M. KENNEDY, JR  
CHIEF, PHYSICS & MATH BRANCH

COMMANDER  
US ARMY MATERIEL DEVELOPMENT  
& READINESS COMMAND  
5001 EISENHOWER AVENUE  
ALEXANDRIA, VA 22333  
ATTN DRXAM-TL, HQ TECH LIBRARY  
ATTN DRCDE, DIR FOR DEV & ENGR  
ATTN DRCDE-D  
ATTN DRCDE-DE  
ATTN DRCMS-I, MR. E. O'DONNELL

COMMANDER  
US ARMY ARMAMENT MATERIEL  
READINESS COMMAND  
ROCK ISLAND, IL 61299  
ATTN DRSAR-LEP-L, TECHNICAL LIBRARY

COMMANDER  
US ARMY MISSILE & MUNITIONS  
CENTER & SCHOOL  
REDSTONE ARSENAL, AL 35809  
ATTN ATSK-CTD-F

DIRECTOR  
US ARMY MATERIEL SYSTEMS  
ANALYSIS ACTIVITY  
ABERDEEN PROVING GROUND, MD 21005  
ATTN DRXSY-MP  
ATTN DRXSY-C  
ATTN DRXSY-T

DIRECTOR  
DEFENSE ADVANCED RESEARCH  
PROJECTS AGENCY  
ARCHITECT BLDG  
1400 WILSON BLVD  
ARLINGTON, VA 22209  
ATTN TECH INFORMATION OFFICE  
ATTN DIR, STRATEGIC TECHNOLOGY OFFICE  
ATTN DIR, TACTICAL TECHNOLOGY OFFICE

DIRECTOR  
US ARMY BALLISTIC RESEARCH LABORATORY  
ABERDEEN PROVING GROUND, MD 21005  
ATTN DRDAR-TSB-S (STINFO)  
ATTN DRDAR-BLB, WEAPON AREA COORDINATORS

TELEDYNE BROWN ENGINEERING  
CUMMINGS RESEARCH PARK  
HUNTSVILLE, AL 35807  
ATTN DR. MELVIN L. PRICE, MS-44

ENGINEERING SOCIETIES LIBRARY  
345 EAST 47TH STREET  
NEW YORK, NY 10017  
ATTN ACQUISITIONS DEPARTMENT

DIRECTOR  
DEFENSE COMMUNICATIONS ENGINEERING CENTER  
1860 WIEHLE AVENUE  
RESTON, VA 22090  
ATTN R104, M. J. RAFFENSPERGER  
ATTN R800, R. E. LYONS

DIRECTOR  
DEFENSE INTELLIGENCE AGENCY  
WASHINGTON, DC 20301  
ATTN DT-2, WEAPONS & SYSTEMS DIV

DIRECTOR  
DEFENSE NUCLEAR AGENCY  
WASHINGTON, DC 20305  
ATTN PETER HAAS, DEP. DIR,  
SCIENTIFIC TECHNOLOGY  
ATTN RAEV, ELECTRONIC VULNERABILITY  
ATTN VLWS, WEAPONS SYSTEMS DIV

UNDER SECRETARY OF DEFENSE FOR RESEARCH  
AND ENGINEERING  
WASHINGTON, DC 20301  
ATTN DEP DIR (TACTICAL WARFARE PROGRAMS)  
ATTN DEP DIR (TEST & EVALUATION)  
ATTN DEFENSE SCIENCE BOARD  
ATTN ASST DIR SALT SUPPORT GP

CHAIRMAN  
JOINT CHIEFS OF STAFF  
WASHINGTON, DC 20301  
ATTN J-3, NUCLEAR WEAPONS BR  
ATTN J-3, EXER PLANS & ANALYSIS DIV  
ATTN J-5, NUCLEAR DIR NUCLEAR POLICY BR  
ATTN J-5, REQUIREMENTS & DEV BR  
ATTN J-6, COMMUNICATIONS-ELECTRONICS

DEPARTMENT OF DEFENSE  
JOINT CHIEFS OF STAFF  
STUDIES ANALYSIS & GAMING AGENCY  
WASHINGTON, DC 20301  
ATTN STRATEGIC FORCES DIV  
ATTN GEN PURPOSE FORCES DIV  
ATTN TAC NUC BR  
ATTN SYS SUPPORT BR

DISTRIBUTION (Cont'd)

ASSISTANT SECRETARY OF DEFENSE  
PROGRAM ANALYSIS AND EVALUATION  
WASHINGTON, DC 20301  
ATTN DEP ASST SECY (GEN PURPOSE PROG)  
ATTN DEP ASST SECY (REGIONAL PROGRAMS)  
ATTN DEP ASST SECY (RESOURCES ANALYSIS)

DEPARTMENT OF THE ARMY  
OFFICE, SECRETARY OF THE ARMY  
WASHINGTON, DC 20301  
ATTN ASST SECRETARY OF THE ARMY (I&L)  
ATTN DEP FOR MATERIEL ACQUISITION  
ATTN ASST SECRETARY OF THE ARMY (R&D)

DEPARTMENT OF THE ARMY  
ASSISTANT CHIEF OF STAFF FOR INTELLIGENCE  
WASHINGTON, DC 20301  
ATTN DAMI-OC  
ATTN DAMI-TA

DIRECTOR  
US ARMY SIGNALS WARFARE LABORATORY  
VINT HILL FARMS STATION  
WARRENTON, VA 22186  
ATTN DELSW-OS

COMMANDER  
US ARMY CONCEPTS ANALYSIS AGENCY  
8120 WOODMONT AVENUE  
BETHESDA, MD 20014  
ATTN COMPUTER SUPPORT DIV  
ATTN WAR GAMING DIR  
ATTN METHODOLOGY AND RESOURCES DIR  
ATTN SYS INTEGRATION ANALYSIS DIR  
ATTN JOINT AND STRATEGIC FORCES DIR  
ATTN FORCE CONCEPTS AND DESIGN DIR  
ATTN OPERATIONAL TEST AND  
EVALUATION AGENCY

DIRECTOR  
NATIONAL SECURITY AGENCY  
FORT GEORGE G. MEADE, MD 20755

COMMANDER-IN-CHIEF  
EUROPEAN COMMAND  
APO NEW YORK, NY 09128

HEADQUARTERS  
US EUROPEAN COMMAND  
APO NEW YORK, NY 09055

DIRECTOR  
WEAPONS SYSTEMS EVALUATION GROUP  
OFFICE, SECRETARY OF DEFENSE  
400 ARMY-NAVY DRIVE  
WASHINGTON, DC 20305  
ATTN DIR, LT GEN GLENN A. KENT

OFFICE, DEPUTY CHIEF OF STAFF FOR  
OPERATIONS & PLANS  
DEPT OF THE ARMY  
WASHINGTON, DC 20310  
ATTN DAMO-RQZ, REQUIREMENTS DIV  
ATTN DAMO-RQD, COMBAT DIV  
ATTN DAMO-SSP, STRATEGIC PLANS & POLICY DIV  
ATTN DAMO-SSN, NUCLEAR DIV  
ATTN DAMO-TCZ, TELECOM & CMD & CONTROL DIR  
ATTN DAMO-ZD, TECH ADVISOR

OFFICE, CHIEF OF RESEARCH DEVELOPMENT  
AND ACQUISITION OFFICE  
DEPT OF THE ARMY  
WASHINGTON, DC 20301  
ATTN DAMA-RAX, SYS REVIEW & ANALYSIS OFFICE  
ATTN DAMA-CSM, MUNITIONS DIV  
ATTN DAMA-WSA, AVIATION SYS  
ATTN DAMA-WSW, GROUND COMBAT SYS  
ATTN DAMA-CSC, COMMAND CONTROL  
SURVEILLANCE SYS DIV  
ATTN DAMA-WSZ-A, DIR, WEAPONS SYS  
ATTN DAMA-WSM, MISSILES & AIR DEF SYS DIV  
ATTN DAMA-PPR, RDTE PROG & BUDGET DIV

COMMANDER  
BALLISTIC MISSILE DEFENSE ADVANCED  
TECHNOLOGY CENTER  
PO BOX 1500  
HUNTSVILLE, AL 35807  
ATTN MISSILE DIRECTORATE  
ATTN TECHNOLOGY ANALYSIS DIV

COMMANDER  
US ARMY FOREIGN SCIENCE AND TECHNOLOGY CENTER  
220 SEVENTH ST, NE  
CHARLOTTESVILLE, VA 22901

COMMANDER  
US ARMY AVIATION SYSTEMS COMMAND  
12TH AND SPRUCE STREETS  
ST. LOUIS, MO 63160  
ATTN DRCPM-AAH

DIRECTOR  
EUSTIS DIRECTORATE  
US ARMY AIR MOBILITY R&D LABORATORY  
FORT EUSTIS, VA 23604  
ATTN SAVDL-EU-MOS  
ATTN SAVDL-EU-TAS (TETRACORE)

COMMANDER  
2D BDE, 101ST ABN DIV (AASLT)  
FORT CAMPBELL, KY 42223  
ATTN AFZB-KB-SO

DISTRIBUTION (Cont'd)

COMMANDER  
US ARMY COMMUNICATIONS RES & DEV COMMAND  
FT. MONMOUTH, NJ 07703  
ATTN PM, ATACS/AMCPM-ATC  
ATTN DRCPM-ATC-TM  
ATTN PM, ARTADS/AMCPM-TDS  
ATTN DRCPM-TDS-TF  
ATTN DRCPM-TDS-TO  
ATTN DRCPM-TDS-FB  
ATTN PM, MALOR/AMCPM-MALR  
ATTN PM, NAVCON/AMCPM-NC  
ATTN PM, REMBASS/AMCPM-RBS

COMMANDER  
US ARMY COMMUNICATIONS & ELECTRONICS  
MATERIEL READINESS COMMAND  
FT MONMOUTH, NJ 07703  
ATTN DRSEL-TL-IR  
ATTN DRSEL-SA  
ATTN DRSEL-MA-C

COMMANDER  
US ARMY MISSILE MATERIEL READINESS COMMAND  
REDSTONE ARSENAL, AL 35809  
ATTN DRSMI-FRR  
ATTN DRCPM-HA  
ATTN DRCPM-LCCX (LANCE)  
ATTN DRCPM-MD, (SAM-D)  
ATTN DRCPM-MP  
ATTN DRCPM-PE, (PERSHING)  
ATTN DRCPM-SHO  
ATTN DRCPM-TO  
ATTN DRSMI-R, RDE & MSL DIRECTORATE

COMMANDER  
US ARMY TANK-AUTOMOTIVE MATERIEL  
READINESS COMMAND  
WARREN, MI 48090  
ATTN DRSI-RHT  
ATTN DRCPM(XM-L)  
ATTN DRCPM-GCM-SW

PRESIDENT  
DA, HA, US ARMY ARMOR AND ENGINEER BOARD  
FORT KNOX, KY 40121  
ATTN STEBB-MO, MAJ SANZOTERRA

COMMANDER  
WHITE SANDS MISSILE RANGE  
WHITE SANDS MISSILE RANGE, NM 88002  
ATTN STEWS-TE-NT, MARVIN SQUIRES

COMMANDER  
TRASANA  
SYSTEM ANALYSIS ACTIVITY  
WHITE SANDS, NM 88002  
ATTN ATAA-TDO

COMMANDER  
197TH INFANTRY BRIGADE  
FORT BENNING, GA 31905  
ATTN COL WASIAK

COMMANDER  
US ARMY COMMUNICATIONS COMMAND  
FORT HUACHUCA, AZ 85613  
ATTN ACC-AD-C, (EMP STUDY GP)

COMMANDER  
USA COMBINED ARMS COMBAT  
DEVELOPMENTS ACTIVITY  
FT. LEAVENWORTH, KS 66027  
ATTN ATCAC  
ATTN ATCACO-SD  
ATTN ATCA/COC  
ATTN ATCA-CCM-F  
ATTN ATSW-TA-E, NUCLEAR STUDY TEAM

PROJECT MANAGER  
MOBILE ELECTRIC POWER  
7500 BACKLICK ROAD  
SPRINGFIELD, VA 22150  
ATTN DRCPM-MEP

COMMANDER  
US ARMY NUCLEAR & CHEMICAL AGENCY  
7500 BACKLICK RD  
BLDG 2073  
SPRINGFIELD, VA 22150  
ATTN ATCN-W, WEAPONS EFFECTS DIV

DIRECTOR  
JOINT TACTICAL COMMUNICATIONS OFFICE  
FT. MONMOUTH, NJ 07703  
ATTN TRI-TAC

CHIEF OF NAVAL OPERATIONS  
NAVY DEPARTMENT  
WASHINGTON, DC 20350  
ATTN NOP-932, SYS EFFECTIVENESS DIV  
ATTN NOP-9860, COMMUNICATIONS BR  
ATTN NOP-351, SURFACE WEAPONS BR  
ATTN NOP-622C, ASST FOR NUCLEAR  
VULNERABILITY

COMMANDER  
NAVAL ELECTRONICS SYSTEMS COMMAND, HQ  
2511 JEFFERSON DAVIS HIGHWAY  
ARLINGTON, VA 20360  
ATTN PME-117-21, SANGUINE DIV

HEADQUARTERS, NAVAL MATERIAL COMMAND  
STRATEGIC SYSTEMS PROJECTS OFFICE  
1931 JEFFERSON DAVIS HIGHWAY  
ARLINGTON, VA 20390  
ATTN NSP2201, LAUNCHING & HANDLING BR  
ATTN NSP-230, FIRE CONTROL & GUIDANCE BR  
ATTN NSP-2701, MISSILE BRANCH

DISTRIBUTION (Cont'd)

COMMANDER  
NAVAL SURFACE WEAPONS CENTER  
WHITE OAK, MD 20910  
ATTN CODE 222, ELECTRONICS &  
ELECTROMAGNETICS DIV  
ATTN CODE 431, ADVANCED ENGR DIV

US AIR FORCE, HEADQUARTERS  
DCS, RESEARCH & DEVELOPMENT  
WASHINGTON, DC 20330  
ATTN DIR OF OPERATIONAL REQUIREMENTS  
& DEVELOPMENT PLANS, S/V

COMMANDER  
AF WEAPONS LABORATORY, AFSC  
KIRTLAND AFB, NM 87117  
ATTN ES, ELECTRONICS DIVISION  
ATTN EL  
ATTN TECHNICAL LIBRARY  
ATTN D. I. LAWRY

COMMANDER  
AERONAUTICAL SYSTEMS DIVISION, AFSC  
WRIGHT-PATTERSON AFB, OH 45433  
ATTN ASD/YH, DEPUTY FOR B-1

COMMANDER  
HQ SPACE & MISSILE SYSTEMS ORGANIZATION  
PO 96960 WORLDWAYS POSTAL CENTER  
LOS ANGELES, CA 90009  
ATTN S7H, DEFENSE SYSTEMS APPL SPO  
ATTN XRT, STRATEGIC SYSTEMS DIV  
ATTN SYS, SURVIVABILITY OFC

SPACE AND MISSILE SYSTEMS ORGANIZATION  
NORTON AFB, CA 92409  
ATTN MMH, HARD ROCK SILO DEVELOPMENT

COMMANDER  
AF SPECIAL WEAPONS CENTER, AFSC  
KIRTLAND AFB, NM 87117

COMMANDANT  
US ARMY COMMAND AND GENERAL STAFF COLLEGE  
FORT LEAVENWORTH, KS 66027

COMMANDER  
US ARMY COMBAT DEVELOPMENTS EXPERIMENTATION  
COMMAND  
FORT ORD, CA 93941

COMMANDER  
HQ MASSTER  
FORT HOOD, TX 76544

COMMANDANT  
US ARMY AIR DEFENSE SCHOOL  
FORT BLISS, TX 79916  
ATTN ATSA-CS

COMMANDANT  
US ARMY ARMOR SCHOOL  
FORT KNOX, KY 40121  
ATTN ATSB-CTD (2 COPIES)

COMMANDER  
US ARMY AVIATION CENTER  
FORT RUCKER, AL 36350  
ATTN ATST-D-MS (2 COPIES)

COMMANDER  
US ARMY ORDNANCE CENTER AND SCHOOL  
ABERDEEN PROVING GROUND, MD 21005  
ATTN USAOC&S  
ATTN ATSL-CTD

COMMANDANT  
US ARMY SIGNAL SCHOOL  
FORT GORDON, GA 30905  
ATTN ATSS-CTD (2 COPIES)  
ATTN AISO-CID  
ATTN ATST-CTD-CS  
ATTN ATSO-CID-CS

COMMANDANT  
US ARMY ENGINEER SCHOOL  
FORT BELVOIR, VA 22060  
ATTN ATSE-CTD (2 COPIES)

COMMANDANT  
US ARMY INFANTRY SCHOOL  
FORT BENNING, GA 31905  
ATTN ATSH-CTD (2 COPIES)

COMMANDER  
US ARMY INTELLIGENCE CENTER AND SCHOOL  
FORT HUACHUCA, AZ 85613 (2 COPIES)

COMMANDANT  
US ARMY FIELD ARTILLERY SCHOOL  
FORT SILL, OK 73503  
ATTN ATSF-CTD (2 COPIES)

US ARMY ELECTRONICS RESEARCH  
& DEVELOPMENT COMMAND  
ATTN WISEMAN, ROBERT S., DR., DRDEL-CT  
ATTN HESS, L., PAO

HARRY DIAMOND LABORATORIES  
ATTN 00100, COMMANDER/TECHNICAL DIR/TSO  
ATTN CHIEF, DIV 10000  
ATTN CHIEF, DIV 20000  
ATTN CHIEF, DIV 30000  
ATTN CHIEF, DIV 40000  
ATTN RECORD COPY, 81200  
ATTN HDL LIBRARY, 81100 (3 COPIES)  
ATTN HDL LIBRARY, 81100 (WOODBIDGE)  
ATTN TECHNICAL REPORTS BRANCH, 81300  
ATTN CHAIRMAN, EDITORIAL COMMITTEE

DISTRIBUTION (Cont'd)

HARRY DIAMOND LABORATORIES (Cont'd)

ATTN WIMENITZ, F. N., 20240  
ATTN PATRICK, E. L., 21500  
ATTN SCOTT, W. J., 21500  
ATTN ROSADO, J., 22000  
ATTN CHASE, R., 21100  
ATTN AGEE, F. J., 21100  
ATTN MILETTA, J., 21100  
ATTN VAULT, W., 22100  
ATTN DANDO, J., 21400  
ATTN CHIEF, 21000  
ATTN CHIEF, 21100  
ATTN CHIEF, 21200  
ATTN CHIEF, 21300 (5 COPIES)  
ATTN CHIEF, 21400  
ATTN CHIEF, 21500  
ATTN GRAY, R., (20 COPIES)