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14. ABSTRACT

This TOP provides methods for planning and execution of testing Army/DOD equipment to determine the effects of Horizontal Component High Altitude Electromagnetic Pulse (HEMP) environment. The content includes facilities, instrumentation setup, new testing procedures, actual environmental considerations, and data recording and presentation of results. Photos of recommended test equipment and test setups are included, along with some representative data plots. This document incorporates the requirements of MIL-STD-464C and MIL-STD-2169C, which provide DOD EMP guidance.

15. SUBJECT TERMS

High-Altitude Electromagnetic Pulse
Advanced Fast Electromagnetic Pulse
Horizontal Electromagnetic Pulse
Nuclear Weapons Effect Testing and Environments

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 01-2-620A — 9 July 2015
DTIC AD No.

HIGH-ALTITUDE ELECTROMAGNETIC PULSE TESTING

* This TOP supersedes TOP 01-2-620, dated 10 November 2011.

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1. SCOPE.

This Test Operations Procedure (TOP) is a general outline of test procedures required to determine the effects of a specified High-Altitude Electromagnetic Pulse (HEMP) environment on Army and/or Department of Defense (DOD) equipment. The purpose of these test and analysis procedures is to ascertain the degree to which the various requirement documents, Concept of Operation (CONOPS), Capability Development Document (CDD), Capability Production Document (CPD), Army Regulation (AR) 70-75[1*], Independent Evaluation Plan (IEP)/Independent Assessment Plan (IAP) criteria, and U.S. Army Nuclear Hardening Criteria (NHC) are met. Army materiel can consist of complete end items, subsystems, line replaceable units (LRUs), components or piece-parts of major systems. All materiel must be tested and analyzed to its NHC with respect to the performance of all its mission essential functions. Realistic hardware, and practical test configurations and scenarios must be tested and analyzed in order to achieve an accurate and complete Electromagnetic Pulse (EMP) Survivability Test and Assessment (STA). All EMP STAs must include a three phase approach in order to meet the requirements of Department of Defense Directive (DODD) 5000.01[2], AR 70-75, and its NHC. To ensure all personnel remain cognizant of the safety hazards associated with HEMP testing personnel and system safety procedures should be observed in accordance with Military Standard (MIL-STD) 882E[3], AR 385-10[4], Department of the Army (DA) Pamphlet (Pam) 385-24[5], and Department of Defense Instruction (DODI) 6055.11[6]. This TOP adheres to an integrated set of test principles and procedures that will result in timely, reliable, and consistent data for HEMP survivability analysis. This document is encouraged for use by all HEMP survivability testers (government and contractor) for test planning, for test conducting, and for acquiring and analyzing data in technical and customer tests in accordance with (IAW) AR 70-75, Director of Operational Test and Evaluation (DOT&E) Electromagnetic Environmental Effects (E3) Policy Memorandum, Deputy Chief of Staff for Operations (DCSOPS) Policy Memorandum, MIL-STD 464C[7], and a Life-Cycle Program (Hardness Assurance). Definitions of terms associated with HEMP testing are provided in Appendix H. Throughout this document, the terms Test Officer (TO) and Project Engineer (PE) are used interchangeably.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Acceptable HEMP test facilities can be categorized as generating horizontally polarized electromagnetic pulse wave early-time event environments. The HEMP test facilities will preferably be certified to meet MIL-STD 2169C[8] by the Defense Threat Reduction Agency (DTRA); and/or HEMP early-time waveforms should be scored against the MIL-STD 2169C parameters. The HEMP simulator uses a dipole antenna configured in a horizontal configuration. HEMP requirements are shown in Table 1. Horizontal polarized simulators should be utilized on systems that can be configured in a low altitude or ground position in order to maximize coupling mechanism to small items such as missiles, small aircraft or those

*Superscript numbers correspond to those in Appendix I, References.

possessing large horizontal coupling paths. Other examples of test items are ground vehicles or launchers that have cabling harness paths in a parallel to ground configuration. Examples of acceptable HEMP facilities are shown in Table 2. Requirements for the Vertical Electromagnetic Pulse are discussed in TOP 01-2-622[9].

TABLE 1. HEMP REQUIREMENTS

ITEM	REQUIREMENT
Horizontal Electromagnetic Pulse Simulator	Test articles with cables or physical structures configured horizontally require Electric Field (E-Field) and Magnetic Field (H-Field) from 25 percent to 160 percent of the MIL-STD-2169C requirement. Pulser simulators and antennas are shown in Figures 1 and 2.

TABLE 2. ACCEPTABLE HEMP FACILITIES

FACILITY	TYPE	LOCATION	COMMENTS
U.S. Army-Horizontal Polarized Dipole (HPD)-II	HPD	Survivability, Vulnerability, and Assessment Directorate (SVAD), White Sands Missile Range (WSMR), NM	1. Max E-Field 50 kV/m. 2. Test Area - extensive space / test volume at low E-Field levels. 3. Quadripartite Standardization Agreement (QSTAG) 244[10], Edition 4 or MIL-STD 2169C system level limited waveform
U.S. Army-Advanced Fast Electromagnetic Pulse (AFEMP)	HPD	SVAD, WSMR, NM	1. Max E-Field 50 kV/m. 2. Test Area – extensive space / test volume at low E-Field levels. 3. QSTAG 244, Edition 4 or MIL-STD 2169C system level limited waveform.
U.S. Navy – HPD	HPD	Patuxent River, MD	1. Max E-Field – 50 kV/m 2. Limited testing volume at higher testing levels. 3. QSTAG 244, Edition 4 or MIL-STD-2169C limited waveform.

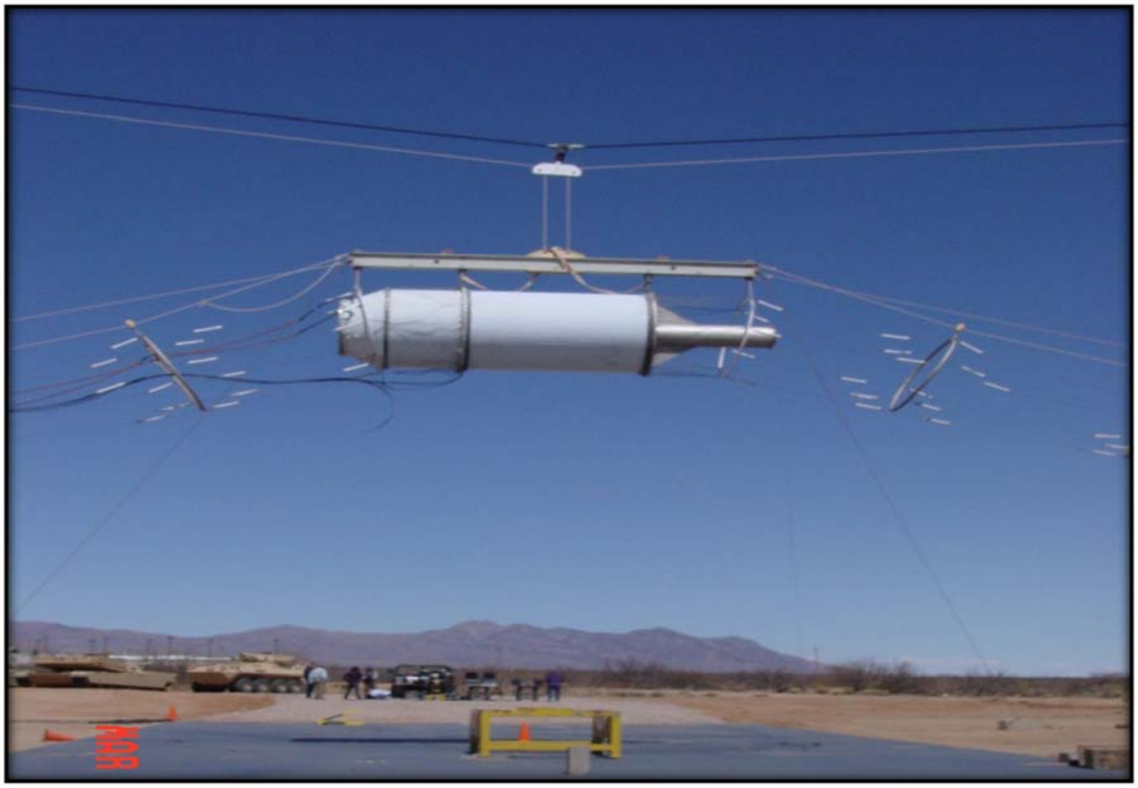

Figure 1. WSMR HPD II HEMP Pulser and Antenna.

Figure 2. WSMR AFEMP Pulser and Antenna.

2.2 Instrumentation.

a. All test facilities are required to have an adequate data acquisition system to record, process, and store data. The shielded room must attenuate transient fields in conformance with standards providing uniform, repeatable measurement. Instrumentation uncertainty and examples of acceptable HEMP instrumentation are as follows:

Devices for Measuring	Permissible Measurement Uncertainty
HEMP Environmental E-Field	2 kV/m or ±5 % (whichever is greater)
HEMP Environmental H-Field	5 Ampere-turns/meter or ±5 % (whichever is greater)
Current	Amperes ±5 %

Measurement Parameter	Preferred Device	Measurement Accuracy
Current	Current probes	±5 %
E-Field	D-dot probe	±5 %
H-Field	B-dot probe	± 5%
Test setup	Digital camera	> 2 mega-pixels

b. The data acquisition system for the free-field tests should consist of transient digitizers with an operating bandwidth of 1 gigahertz (GHz), with a 1 Giga-sample per second sampling rate. Fiber optic data transmission systems must be equal to the operating bandwidth of the digitizers. All utilized probes must be responsive to at least 1 GHz. Figure 3 shows a typical data acquisition system. In order to simplify the figure, Figure 3 depicts a Ferrite Cable of 2 meters long; however, the cable used can vary in length but maximum length is 2 meters.

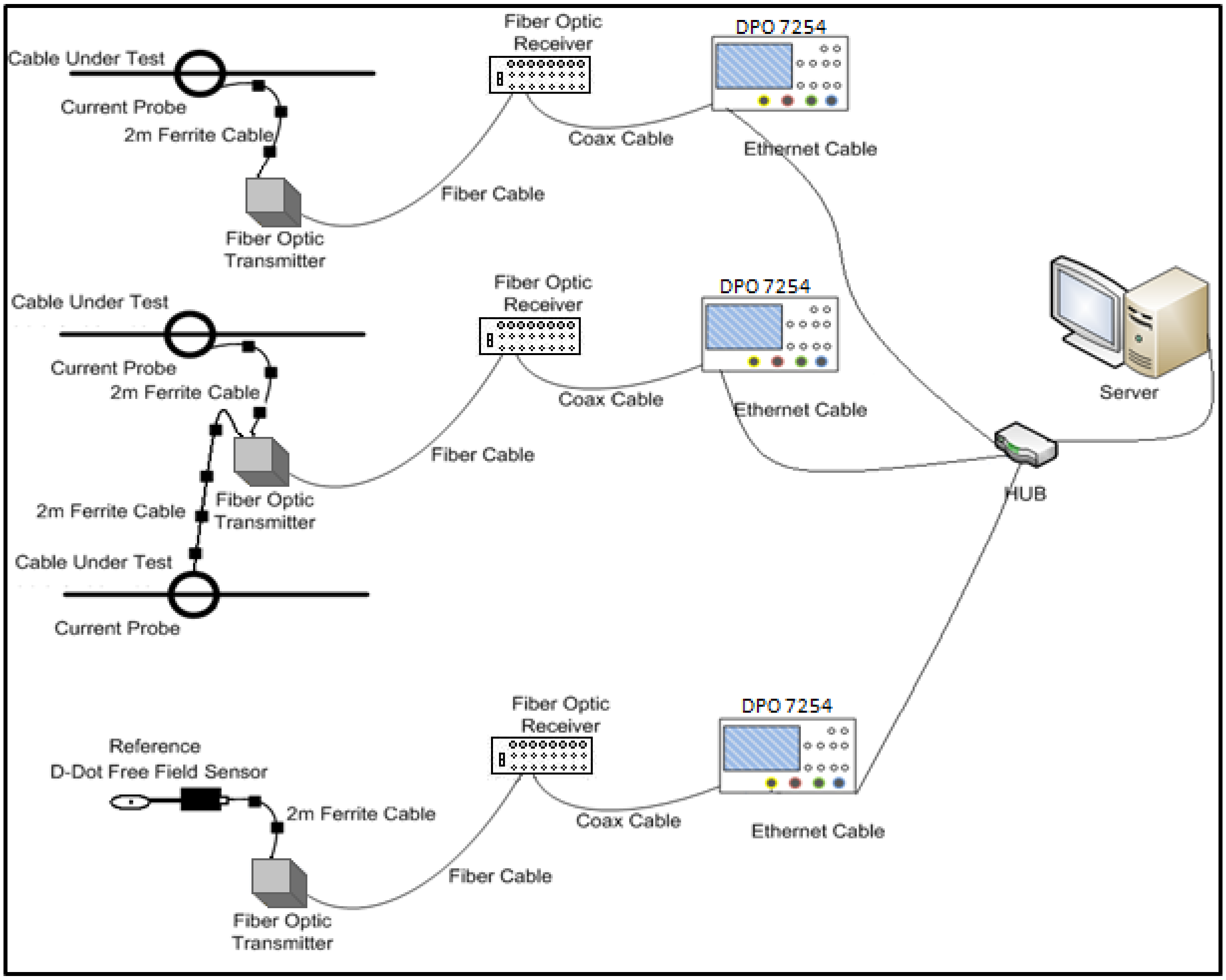

Figure 3. Data acquisition system.

c. Measurements of each illumination must be monitored by a B-dot probe (measures the time rate of change in the H-Field) or D-dot probe (measures the time rate of change in the E-Field) so that the magnitude of the E-Field and pulse shape information is obtained. This information should be digitized, analyzed, and stored for a later detailed analysis and review.

d. A computer is used for data recording and signal processing. It allows the storage of large amounts of data and the ability to perform signal processing (such as Fast Fourier Transforms (FFTs)). All information can be stored into a database for quick access and further analysis. Finally, the processed data can then be used for other phases of the HEMP hardness assurance process as well as input into other HEMP test programs and life-cycle programs.

e. All test and measurement instrumentation is required to be characterized and calibrated to insure accurate data and as a necessary component of the data reduction process.

2.3 HEMP Pre-/Post Test Illuminations.

a. The following four criteria parameters along with the System Under Test (SUT) allowable down time must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

HEMP Parameter	Units	Parameter Tolerance
Electric Field – E-Field	Volts/meter	±5 %
Magnetic Field – H-Field	Amp-turns/meter	± 5%
Risetime	Nanoseconds	± 5%
Pulse width	Nanoseconds	± 5%
SUT allowable downtime	Minutes	±1 minute

b. Performance criteria of the test system include allowable downtime and recovery procedures, operate through performance, acceptable damage and degradation, re-boot, the availability of the SUT, and time required to implement repair with replacement parts from the system support package.

3. REQUIRED TEST CONDITIONS.

The TO or PE must ensure that the HEMP test facility utilized is an adequate facility to accurately simulate the criteria, test system response, and is adequate to test the system in a fielded configuration. It is emphasized that available facilities will provide only a simulated HEMP environment. Therefore, in addition to valid test data, adequate analysis must be performed to account for the facility deficiencies as theater wide surrogate. Facility deficiencies must be known, quantified, and documented.

3.1 Test Preparation.

3.1.1 Scope of Testing.

a. The HEMP system level testing cannot begin without the development and approval of a detailed test plan. The detailed test plan must include well defined objective(s) for the test and a set of criteria for the SUT. The detailed test plan should include (among other things): a listing and analysis of prior HEMP testing (especially testing at the LRU and subsystem levels), a listing and short description of the LRUs and subsystems which are mission critical, delineate what measurements are needed, explain how the required data are to be measured, define special test equipment needed, and describe how system response to HEMP is to be analyzed.

b. In order to maximize test time and resources (i.e., manpower, and money) it is very important that all data that are generated from HEMP testing and analysis at the LRU/subsystem and component level, be collected and assessed prior to the commencement of system level testing. The rationale for this step is to provide structure to the test program by identifying whether any problems seen at the lower levels of assembly may be significant at the system level, hence; efforts can be focused on resolving these problems. Any deficiencies determined during testing at the LRU/subsystem level can be addressed during the system level test. All anomalies, upsets, and burn-outs (hardware replacement) will be scored against the SUT's failure definition and scoring criteria (FD/SC) and labeled IAW the SUT's security classification guide (SCG).

c. Identification of mission critical functions and the hardware that perform such functions MUST be identified prior to the start of the test. This serves the purpose of providing the required data for the objectives and structure of the test program. The resulting HEMP test can then be structured to provide the data to meet those objectives.

3.1.2 HEMP Illumination Testing.

a. This test will be conducted in compliance with all relevant site Standard Operating Procedures (SOPs) for the specific test facility used. In addition, any special safety procedures to be followed for the duration of the testing should be established. Security procedures to be followed for the tests are to be established from the system SCG.

b. The HEMP simulation facility shall have a measured map of the peak amplitude waveform of the electromagnetic field at various locations within or around the test volume to insure that desired output characteristics can be reproduced prior to the test. The output characteristics of the facility should not vary more than 20 % from what is specified by the criteria. A reference peak E-Field measurement is recorded to assure that mapping data and field data are correlated.

c. All current probes and fiber optics are to be characterized to insure that the equipment is within specified performance tolerances. Characterization must be performed to ensure that the correct metrics (e. g., E-Field levels, voltages, currents, etc.) are being accurately measured and that the variance between pulses can be established for post test analysis. This in turn will be used to determine the accuracy of the simulation.

d. A list of cable/harness measurements and wire/pin current measurement test points will be developed and forwarded to the facility for labeling and included in the final test report. The test points are to be identified and prioritized. Cables and wires on the system are to be tagged and a test sequence for their measurement established. The information is to be recorded on the facility data forms.

e. If prior test data from LRU and subsystem tests exists, then their results should be incorporated as part of the test plan to identify the expected coupling levels. The data will then be compared. In those cases where there is insufficient test data from prior program testing, a HEMP analytical model providing pre-test predictions should be used and the results passed on to the data collectors. The necessity of this step is threefold:

(1) For most systems, it is not feasible (in terms of cost, and time) to have all mission critical test points measured for all possible operating states of the system under test. The development of a model serves to provide predictability of the HEMP coupling process and gives the analyst a method for computing the transient pin currents and voltages on critical test points not measured in the system level test program. An analysis for these circuits can then be performed.

(2) Any deviations between the predicted and measured responses are indicators that unforeseen coupling mechanisms (unknown variables, nonlinearities) are present. This information then allows the system configuration to be verified and aids in the refinement of the HEMP coupling model. The new model can then be used as input into other phases of the HEMP program for that system's lifecycle.

(3) The prior data or predictions will allow the data collector to reduce test time expended for tuning settings, triggers, and biases for the data collection equipment.

f. Test configurations and orientations must be identified for each test level during the pretest analysis. The approximate number of pulses per configuration and/or orientation is estimated based on available data channels and number of test points to be measured. This aids in the scheduling of test time at a facility.

g. The test officer/project engineer (TO/PE) must thoroughly document and analyze the test hardware which is to be utilized during the HEMP STA. This documentation includes the test system's material composition, shape, size, mass, fastening schemes, shielding and attenuation characteristics, EMP hardening concepts, complementary system connections, and Mission Essential Functions (MEFs). The TO/PE will identify and establish the test system and proposed system baseline configuration with this information. This baseline will be utilized for the survivability analysis as well as a basis for analysis of all product improvements, Engineering Change Proposals (ECPs), and configuration changes to ensure that the test system remains HEMP survivable during production, maintenance, and deployment to include life-cycle monitoring.

h. The TO/PE must analyze and determine the test system's performance with a detailed post-test analysis. This post-test analysis includes test environments and results of the pre-test analysis, documentation and detailed determination of the test system's performance, determination of all shortcomings and failures, and determination of obtained environmental electromagnetic field data against the Army criteria issued by the United States Army Nuclear and Combating Weapons of Mass Destruction Agency (USANCA). In order to effectively determine criteria compliance, the TO/PE must thoroughly understand the simulation fidelity of the test facility and its documentation and procedures to account for fidelity deficiencies. The result of the pre-test analysis is used to obtain a high confidence of collecting the required evaluation data for the SUT prior to the start of testing. All test facilities have one or more parameter deficiencies. Therefore, these deficiencies must be well understood, and an analysis must be performed to establish the effects of facility deficiencies on the results of the test. The

TO/PE can adequately determine the electromagnetic fidelity against the required Army criteria issued by the USANCA with an analysis of the deficiencies factored into the collected data. In order to effectively analyze survivability of the system configuration, the TO/PE must thoroughly understand the differences between the test system and the system's production configuration. These differences should be addressed in the system analysis.

3.2 Test Execution.

3.2.1 Pretest Analysis/Modeling/Sub-threat Test Assessments.

a. Before the execution of any HEMP test program, a pretest analysis must be performed. During the pretest analysis, the TO/PE must thoroughly examine the SUT, extrapolate engineering calculations, and estimate HEMP responses to determine where potential coupling and survivability problems may exist. Predictions of EMP results may include EM modeling techniques and sub-threat level test evaluations where appropriate. The TO/PE must determine appropriate test facility capabilities, cost, and schedule to ensure that the appropriate facility is used, adequate data acquisition is available, and the required test configurations/orientations are tested. Sub-threat level test and analysis can be an efficient way to reduce cost by eliminating unnecessary configurations/orientations being performed in the threat level facility. In order to perform an adequate pretest analysis, the TO needs (if available) accurate schematics, parts lists, details of deliberate hardening methods/hardware, previous test results (including all pertinent EM modeling studies and all sub-threat level assessments) and/or analytical data, material composition, wiring diagrams, and cable shielding specifications. Based on the pretest analysis (including modeling/sub-threat evaluations) and system inspection, the TO can establish functional modes and system configurations where significant data can be obtained on the expected performance of the test system from the threat level HEMP environment. The pretest analysis should be the determination of susceptibility of interface devices accessed by individual conductors. If more data are necessary, a breakout box may be used to separate the conductor for induced current measurements. The orientations of the SUT in respect to the electromagnetic environment should be identified and set up for each test system illumination.

b. The SUT will only be subjected to the Early-Time Electric-Field (E-Field) Waveform (E1) of MIL-STD 2169C HEMP environment. The HEMP environment has two additional E-Field Waveforms, E2 for Mid-Time and E3 for Late-Time. These two waveforms are not being considered in this TOP because of their limited applicability to tactical mobile systems. These waveforms are applicable for systems connected by very long cables (E2) or to systems connected to the power grid or communications lines (E3). These waveforms should be verified for strategic, fixed site located military systems. Line impedance stabilization networks will be used to control the impedance of the power source providing input power to the SUT.

3.2.2 Project Engineering Judgment.

During the entire execution of the HEMP test, the TO/PE must utilize project engineering / management judgment to effectively test and analyze the data and maintain schedules and costs. Engineering judgment becomes critical when schedule impacts occur such as facility downtime, inclement weather, failures and/or re-prioritization. Under such conditions, the TO/PE must determine the problem, deviate from the original test plan, and devise an alternate plan or set of procedures. The TO/PE must also devise work arounds that maximize the completion of testing and meet the test objectives. Any deviations from the test plan shall be recorded and reported in the test report.

3.3 Test Reporting and Life-Cycle of Survivability Programs.

a. The production, operation, maturity, storage, maintenance, modification, and ambient environments must not introduce unacceptable levels of degradation into HEMP survivability of a system scored against the criteria. To ensure continued HEMP survivability, a Life-Cycle Nuclear Survivability (LCNS) program must be established IAW the NHC, AR 70-75, DODD 5000.01, and the DODI 3150.09[11]. The basic purposes of the LCNS program are to monitor all changes to the baseline configuration during production and product improvements, ensure that an acceptable hardness level is preserved during maintenance by using certified spare parts and procedures, and verifying that the hardness level is not degraded to an unacceptable level during fielding, storage, and operating in the specified weather environments.

b. The pre-exposure and post-exposure SUT operation data and system check data, along with the environmental weather exposure data and specification requirements, will form the basis of the analysis to determine the effects of the HEMP environment on the SUT performance capabilities. This analysis will enable a survivability evaluation to be performed.

c. The recorded current data will be processed to indicate peak current ($I_{amperes}$) and primary damped sinusoidal frequency. In the event of system upset or failure, this frequency data can be used in developing corrective actions. Pertinent data results and information will be archived into the system or sub-system program life-cycle database for future evaluations, hardness and sustainment assurance, and surveillance test updates.

3.3.1 Statistical and Error Analysis.

Other forms of analysis that should be considered or performed on the test data are statistical and error analysis. The TO/PE should use statistical analysis to obtain the criteria compliance between actual electromagnetic environment parameters and the required criteria. An error analysis should be performed to account for and eliminate sources of error present in the raw test data. Possible sources of error that should be examined are: instrumentation and data acquisition, human interpretations, test setup, probe, and numerical data round-off. The TO/PE utilizes this error analysis to help predict how accurate the simulated test environment was to the specified Army environment issued by the USANCA to ensure that the test system is stressed to the HEMP survivability criteria including the predicted error.

3.3.2 Test Record / Report Process.

a. After the TO/PE has completed all the test execution, data analysis, and survivability analysis, a detailed test report or test record must be written IAW the U.S. Army Test and Evaluation Command (ATEC) Pam 73-1 (Volume I)[12]. It is critical that all required steps in ATEC Pam 73-1 are followed. The test record / report must be completed and submitted to

ATEC not later than (NLT) the time frames specified in Table 5.2 of ATEC Pam 73-1 after the test completion. The qualification report for programs of record must be approved by ATEC for release. Test Records / Reports should contain the following information:

Foreword.

I. Section 1: Executive Digest.

1.1 System Description.
1.2 Summary.
1.3 Conclusions.
1.4 Recommendations.

II. Section 2: Subtests. (for each test environment).

2.1 Name of Subtest.
2.1.1 Objectives.
2.1.2 Criteria and Analysis.
2.1.3 Test Procedure and Findings.

III. Section 3: Appendices.

A. Test Criteria.
B. Test Data.
C. Recommendation for Classification of Risk.

b. If no additional appendices are required to adequately quantify the test results and findings, the following appendices are required to close the test report and will be lettered consecutively:

D. References.
E. Abbreviations.
F. Distribution List.

4. TEST PROCEDURES.

4.1 Test System.

Survivability of the test system when exposed to the simulated HEMP environment will be analyzed by:

a. Performing the detailed pretest analysis, TO/PE responsibility.

b. Calibrating required data acquisition systems (DAS), facility responsibility.

c. Establishing the performance and operational baseline for the test system prior to testing, TO/PE responsibility.

d. Determining effects by repeating the performance and operational baseline checks or abbreviated checks after each illumination, TO/PE responsibility.

e. Illuminating the test system in the pre-selected orientations, configurations, and modes at 0.5, 1.0, and 1.5 times its E-Field criterion level as defined in the pretest analysis phase. When deemed appropriate and achievable by the TO/PE, other levels such as 0.75 and 2.0 times (IAW MIL-STD-464C) will be performed. Determining all upsets, failures, downtimes, mission performance impacts, and corrective actions, TO/PE responsibility.

f. Analyzing response, TO/PE responsibility and correcting the environmental data, facility responsibility.

g. If the system cannot be tested to an adequate simulated environment or exceeds the facilities physical dimension test capability; then current injecting external connections should be used at 1X, 3X, and 5X the baseline signals and/or damped sinusoidal waveforms obtained from conducted susceptibility (CS) 115 and CS116 in MIL-STDs-461F[13] and 464C references, TO/PE responsibility.

h. Recording and analyzing system induced currents in both the time and frequency domains, facility responsibility.

i. The TO/PE must ensure that accurate, consistent, and documented operational checks are utilized. Many of the problems induced by the illumination will be transient upsets and will be correctable by cycling power.

4.2 Baseline System Under Test.

The survivability of the baseline system configuration when exposed to the HEMP Army criteria issued by the USANCA will be analyzed by:

a. Analyzing the differences between the tests's simulated electromagnetic environment and Army criteria issued by the USANCA, facility responsibility.

b. Analyzing the differences between the SUT baseline and production configurations, TO/PE responsibility.

c. Determining the response of the SUT configuration according to the system performance requirements, to include allowable down time after illumination to the HEMP environment, to the Army criteria issued by the USANCA, TO/PE responsibility.

4.3 Test Setup.

Prior to testing, the complete test system will be analyzed to ensure proper operation and establish the performance baseline. All problems identified will be documented and corrected if detrimental to the HEMP test program. The test facility will perform calibration and noise measurements on the DAS to ensure that accurate data acquisition will be achieved. The DAS utilized must account for all introduced error and be adequately protected against EM interference. The test system will be positioned in its first orientation in the facility's test volume based upon facility mapping data. Current and/or voltage probes will be positioned based on information obtained from the pretest analysis; breakout boxes will be installed if required. The baseline or abbreviated baseline checks will be performed. Test setup photographs will be taken. These procedures will be repeated for each test orientation and configuration at each test level.

4.4 Test.

The test system will be illuminated by simulated HEMP waveforms. After illumination, the test system will be analyzed to identify and quantify effects by using the pretest baseline checks and diagnostic checks, if necessary. Test probes will be repositioned, if required, and the test system will be illuminated again. This procedure will be implemented until sufficient data are obtained for all functional modes and system configurations on all cables identified in the pretest analysis. At the completion of the first successful test system orientation, the system's orientation will be altered IAW the pretest analysis and test plan unless the test results dictate differently. Once adequate data are obtained for the initial test level, the test level will be incremented as specified in paragraph 4.1.e. The levels specified in paragraph 4.1 can be altered based on engineering judgments of the results/effects of the on-going test. Multiple illuminations or a substantial test sample size must be utilized to provide statistical confidence in the HEMP survivability of the test system. Failures and significant upsets will be diagnosed as to causes and impacts on the mission. Responses and electromagnetic environmental data will be processed, analyzed, and reported. All pertinent data will be analyzed. The four critical test electromagnetic environmental parameters (i.e. electric field intensity, rise-time, pulse-width and polarization) will be analyzed against the Army criteria issued by the USANCA to determine criteria compliance. These criteria compliances must be utilized in correcting induced and projected responses to the test system and baseline configuration, respectively.

5. DATA REQUIRED.

a. Detailed description of the method and facility for producing the HEMP environment, to include photographs of the test facility setup, showing test system location relative to the HEMP source.

b. Complete set of pretest mapping data of the facility with the E-Field expressed in Volts/meter (±5 %), rise-time and pulse width expressed in nanoseconds (±5 %), frequency expressed in Hertz (±5 %), and H-Field amplitude expressed in Amp-turns/meter (±5 %).

c. Results from the pretest analysis, to include data from the contractor's HEMP test/analysis programs as well as other such programs performed on similar military systems.

d. Detailed description of system performance and operational checks utilized to baseline the system and determine its post-illumination operational status.

e. Complete list of all electronic piece-parts utilized in the test system to support EMP protection.

f. Complete set of electrical schematics and interconnect diagrams.

g. Detailed description, serial numbers, and dimensions of each subsystem of the test system.

h. Detailed description of all system cables to include type, composition, and dimensions.

i. Detailed description of all back shells and connectors, to include attachment methodology, type, and composition.

j. Detailed description of the grounding scheme utilized on the test system.

k. Complete list of safety and environmental concerns.

l. Detailed description of all mission essential functions.

m. Detailed description of all deliberate electromagnetic hardening techniques/hardware, to include manufacturer's specifications.

n. Detailed description of pretest selected system configurations, orientations, and modes utilized during the test.

o. Detailed description and documentation of all inspections, downtime (sec) (±10 %), performance and operational checks, and maintenance procedures.

p. Detailed description of the facility's data acquisition system, to include probe calibration data, noise measurements, hardware and software.

q. Detailed description of utilized current and voltage probes, breakout boxes (BOBs) and probe locations employed on the test system.

r. Results of all HEMP environment and test point measurements, to include real time response and FFTs.

s. Results obtained from the pretest Current Injection (CI) tests (if required based on facility capabilities and test system size).

t. Detailed description of the method and facility producing the CIs (if required).

u. Detailed description of recovery procedures and time.

v. Results of all energy coupling and protection hardware analysis, to include Design Margins (DMs).

6. PRESENTATION OF DATA.

6.1 Data Appropriation and Compliance.

a. Results from the pretest analysis, and all other applicable HEMP survivability programs will be analyzed and whenever possible, incorporated into all facets of the HEMP STA on the test system. The incorporation of all available analytical and test data will be used to enhance and reduce the overall scope of the test program.

b. Data from free-field environment measurements will be utilized to define the test environment and quantify the differences between the test and criteria environments. Differences greater than fifteen percent between the criteria parameter values and the simulated parameter values will be analyzed to determine the effect on the test results. Procedures and analysis utilized will be clearly documented.

c. Results from the pretest analysis, system test and post-test determination/analysis, and environment compliance will be integrated into an assessment of the survivability of the test system's configuration to the test and then the Army criteria issued by the USANCA. The final assessment of the test system may show different damage and mission impacts than the test results due to extrapolation and correction of environmental and test data to account for variances and differences.

d. The Army HEMP requirements issued by the USANCA are usually derived from the following documents:

(1) QSTAG 244, Edition 4: Nuclear Survivability Criteria for Military Equipment.

(2) QSTAG 620, Edition 2[14]: Nuclear Survivability Criteria for Communications-Electronics Equipment.

(3) MIL-STD-2169C: High Altitude Electromagnetic Pulse (HEMP) Environment. The final survivability analysis of the baseline system configuration to the Army requirements issued by the USANCA will utilize, incorporate, and integrate the data and results of the test system survivability determination and analysis of the production configuration differences. This final survivability assessment of the baseline configuration may show results different than the test system analysis due to extrapolations and/or corrections for configuration differences.

6.2 Data Reduction.

a. All raw data collected during HEMP survivability testing must be processed to remove data acquisition error and to define simulation deficiencies. All analytical procedures and methods utilized to process these raw data must be documented along with example calculations in “Appendix B: Test Data" of a detailed test report. The entire collection of raw data should not be presented in the test report because of its excessive bulk. Reduced data that are pertinent to the analysis and support the determinations should be included in tabular form in the main body.

b. The data must demonstrate that the test hardware was adequately tested to its specified criteria. The HEMP environment parameters will then be processed and combined with the pretest results, along with the data analyzed, so that the accuracy of the test configuration can be determined. Analytical techniques such as PSpice (circuit and logic simulation software), frequency analysis, and curve fitting must be discussed with constraints and inputs to enable the reader to determine the adequacy of the testing. All analytical data reduction methods must be identified and presented in Appendix B of the test report and must include pertinent HEMP data in both the frequency and time domains.

c. Statistical analysis such as computing the mean, standard deviation, DMs, and criteria compliance percentages should be performed on all HEMP survivability system test data. The type and quality of data will determine the statistical methods to be employed.

6.3 Data Presentation.

Data must be presented in a clear and concise manner, so they are easy to understand and support the conclusions regarding the HEMP survivability of test item/system hardware as depicted in the Appendices. To accomplish this, a combination of charts, graphs, drawings, tables, and photographs should be utilized. Tables 3 and 4 give examples of current probe measurement results and calculations of test items being monitored during HEMP testing. Figure 4 illustrates a corrected data plot of a current probe measurement.

TABLE 3. CURRENT PROBE MEASUREMENTS

TestID	Shot#	Peak I	Peak Derivative	Peak Impulse	Rectified Impulse	Root Action Integral	Total Energy
Sample 1	2813	-8.58699	5.23E+09	2.08E-07	9.92E-07	0.00177533	3.15E-06
Sample 2	2814	37.8424	1.58E+10	4.32E-07	2.50E-06	0.00578212	3.34E-05
Sample 3	2814	20.1759	8.98E+09	3.54E-07	1.68E-06	0.00358034	1.28E-05

TABLE 4. CURRENT PROBE CALCULATIONS

TestID	Shot#	Peak I	ResFreq	LowFreq	HighFreq	Bandwidth	Alpha	Q	dampfactor
Sample 1	2813	-8.58699	1.35E+07	1.27E+07	1.43E+07	1.66E+06	5.23E+06	8.08668	0.06183
Sample 2	2814	37.8424	2.60E+07	2.32E+07	2.73E+07	4.10E+06	1.29E+07	6.34501	0.078802
Sample 3	2814	20.1759	1.10E+07	1.02E+07	1.43E+07	4.14E+06	1.30E+07	2.65824	0.188094

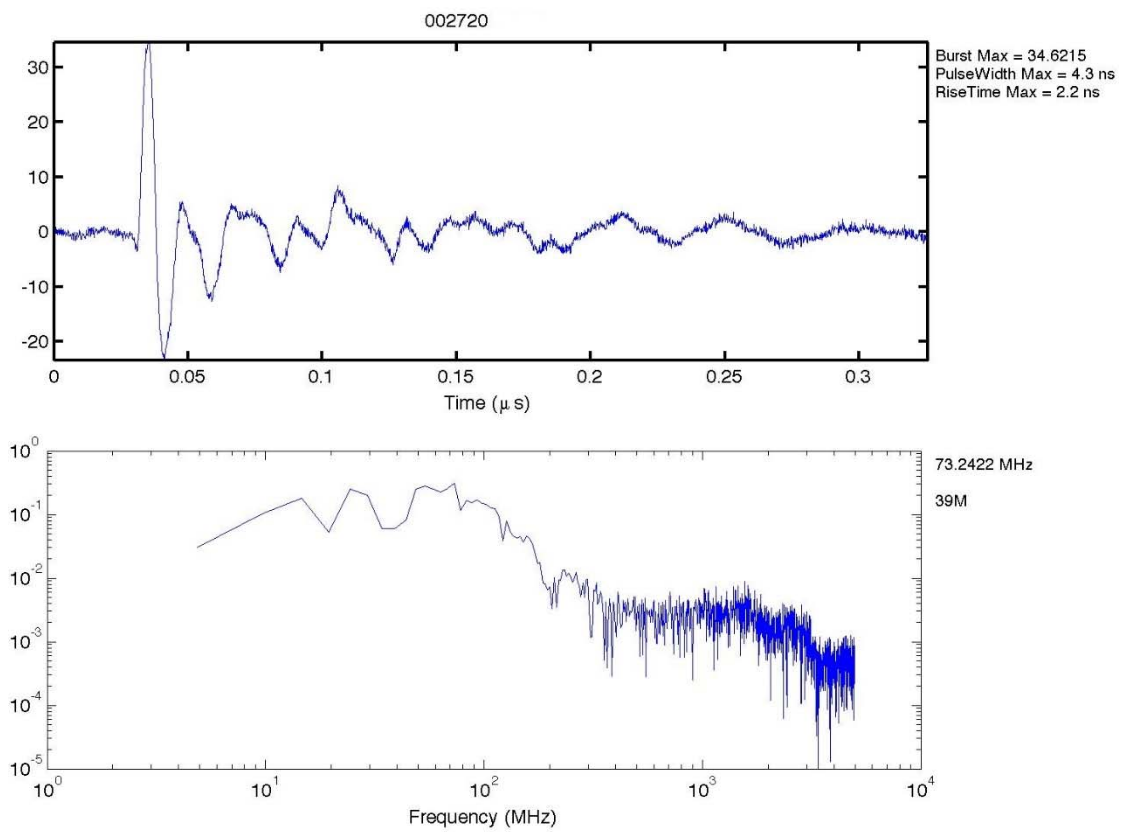

Figure 4. Corrected Current Probe Measurement.

a. Tables should be utilized to present the following data:

(1) Illumination test results summary.

(2) Equipment test matrix.

(3) Criteria compliance.

(4) Test point reduced data.

(5) Statistical analysis.

(6) Criteria and test standards.

(7) Test comparisons.

b. Photographs should be utilized to present the following data:

(1) Test configurations, orientations, and set-ups.

(2) Test facility's data acquisition set-up.

(3) Locations of other utilized measuring devices.

(4) Test facility layout.

(5) Visible damage.

c. Drawings should be utilized when photography is not available or inadequate to display critical data supporting the results and/or conclusions.

d. Charts and graphs should be utilized to present the following data:

(1) Test schedules.

(2) Criteria compliance.

(3) Previous test comparisons.

(4) Comparisons of test point data with the test item in different configurations, orientations, or modes.

(5) Test program status.

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APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

A.1 The electromagnetic environment produced by a nuclear weapon consists of the ionization of the atmosphere and generation of an EMP. The gamma rays, neutrons, beta particles, X-rays, and positive ions emitted from the nuclear detonation causes electrons to be ejected from their perspective atoms, thus ionizing the atmosphere in the burst vicinity. This increase in electron density attenuates or refracts all electromagnetic signals from a few seconds to several hours depending on weapon yield and height-of-burst (HOB). Radio communications depend on propagation of transmitted waves through the atmosphere. Depending on the specific frequency, this propagation occurs in one of two paths, ground or sky waves. Low frequencies utilize the ground wave path, while the high frequency band utilizes the sky wave path which is reflected back to earth by the ionosphere. Very High Frequency (VHF) and Ultra High Frequency (UHF) penetrate the ionosphere; therefore, any disturbance in the ionosphere does not affect communications in these frequency bands. See Table A-1 for frequency band effects caused by atmosphere ionization.

TABLE A-1. FREQUENCY BAND EFFECTS CAUSED BY ATMOSPHERE IONIZATION

BAND	FREQUENCY RANGE	EFFECTS ON COMMUNICATIONS
Very Low Frequency (VLF)	3 – 29.9 kilohertz (kHz)	Limited effects
Low Frequency (LF)	30 – 299.9 kHz	Drastic reduction of sky wave path, but no effects on ground wave path
Middle Frequency (MF)	300 – 2999.9 kHz	Same as LF
High Frequency (HF)	3 – 29.9 MHz	Considerable effects
VHF	30 – 299.9 MHz	Limited effects, but propagation enhancement possible
UHF	300 – 2999.9 MHz	Limited effects
RADAR	3000 – 9999.9 MHz	Attenuated and refracted

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

A.2 A nuclear detonation distributes approximately one millionth of its energy in the form of an intense EMP with a frequency content of a few hertz (Hz) to several hundred MHz. The area affected by EMP and the characteristics of the pulse, is a function of burst altitude and weapon design and yield. Typical EMP intensity is in the order of tens of thousands of volts/meter. This compares with the order of 200 volts/meter for nearby radars, 10 volts/meter for communication equipment, and 0.01 volts/meter for typical metropolitan area ambient. Two characteristics of EMP which result in a threat to electrical equipment are field amplitude and broad frequency spectrum. There are three basic mechanisms for EM coupling to a conducting structure: electrical induction, the basic mechanism for linear conductors; magnetic induction, the principal mechanism when the conducting structure forms a closed loop; and earth transfer impedance for buried conductors. Devices which may be susceptible to functional damage due to electrical transients include active electronic devices, passive electronic components, semiconductor devices, squibs and pyrotechnic devices, meters, and power cables. Operational upset can be expected in digital processing systems, memory units, guidance systems, and power distribution systems. Damage mechanisms include dielectric breakdown, thermal effects and interconnection failures. The two EMP situations which are based upon burst altitude are (Endo-Atmospheric) Source Region Electromagnetic Pulse (SREMP) and (Exo-Atmospheric) High Altitude Electromagnetic Pulse (HEMP).

A.3 The first EMP situation, SREMP, occurs within the atmosphere at an altitude of less than 40 km above sea level, and possesses an extremely large electric and magnetic field over the burst vicinity. Of particular concern are events at or within 1 km of the surface. Only within these limits are tactical surface systems close enough to the event to have the potential to be adversely affected by SREMP. SREMP is generated by collisions between photons from gamma radiation and molecules of the atmosphere. These highly energetic photons eject electrons from the surrounding air molecules, producing ionized air molecules. This immense separation of charge creates an intense E-Field of several 100,000 volts/meter and a large associated H-Field of 500 ampere-turns/meter. Ninety percent of its energy is contained in the 100 Hz to 10 kHz range. See Figure A-1 for an example of the SREMP waveform and Figure A-2 for relative energy versus frequency for an Endo-Atmospheric Burst.

A.4 The second EMP situation, HEMP, occurs at an altitude greater than 40 km above sea level, and possesses a large electric and magnetic field over a diverse area. This tremendous area of effects is the reason HEMP is considered militarily significant and the more damaging of the two EMP situations. The HEMP is generated by gamma photons being absorbed by the atmospheric molecules at altitudes from 20 to 40 kilometers. This absorption causes electrons to be deflected by the earth's magnetic field into a spiral path about the field lines, causing them to radiate electromagnetic energy. See Figure A-3 for formation of HEMP and Figure A-4 for the detailed geometry of this phenomenon.

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

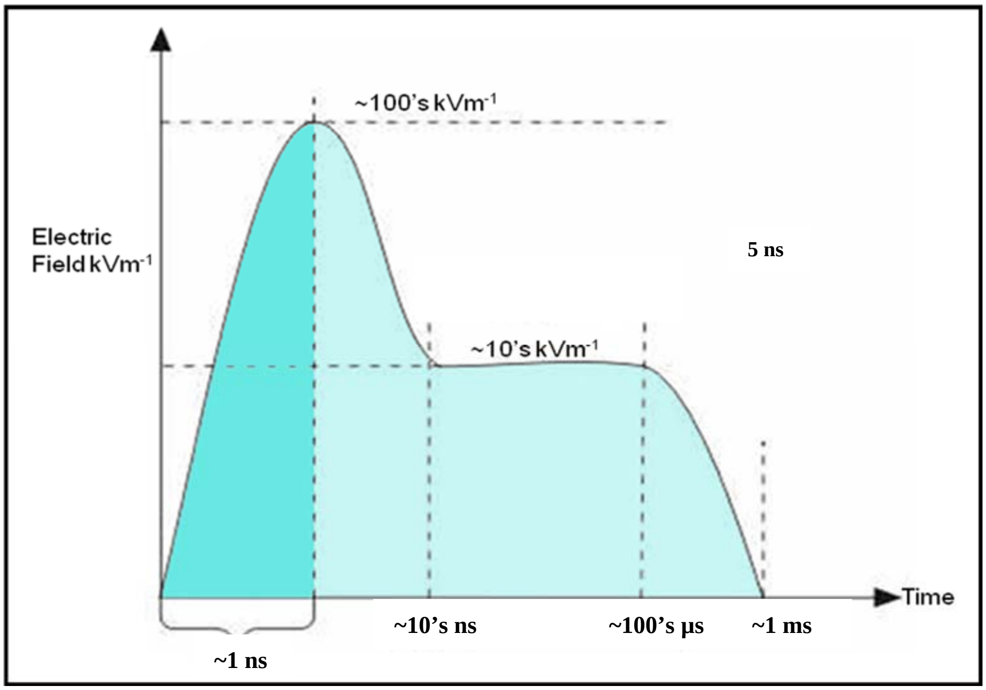

Figure A-1. Endo-Atmospheric EMP waveform.

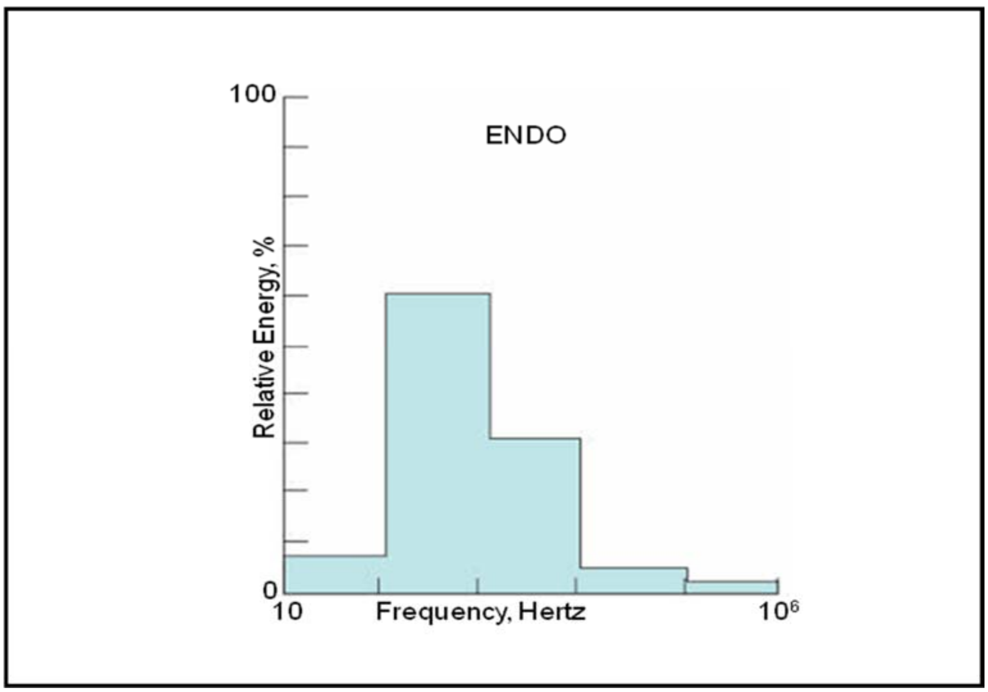

Figure A-2. Endo-Atmospheric relative energy versus frequency.

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

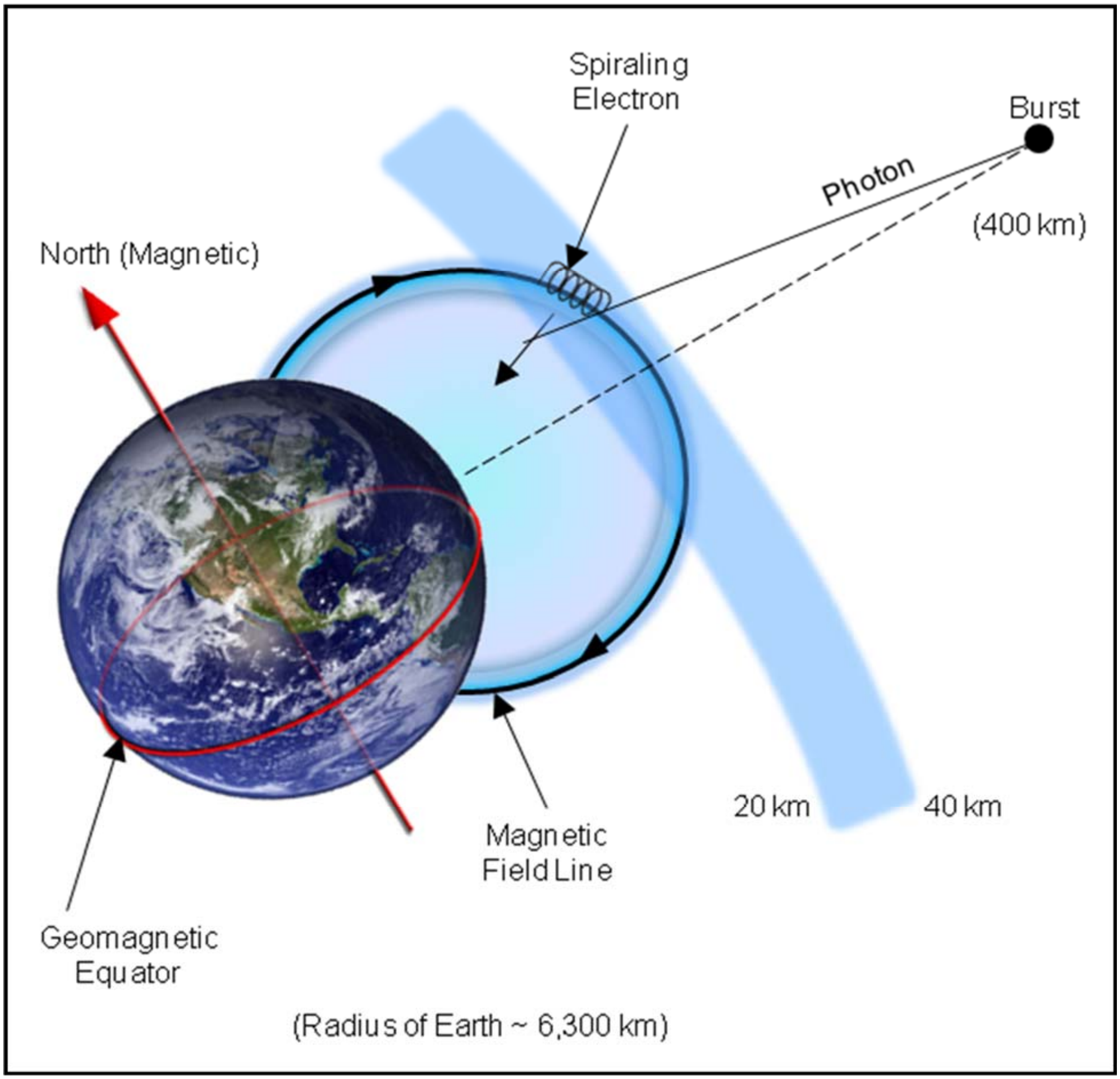

Figure A-3. Formation of Exo-Atmospheric EMP.

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

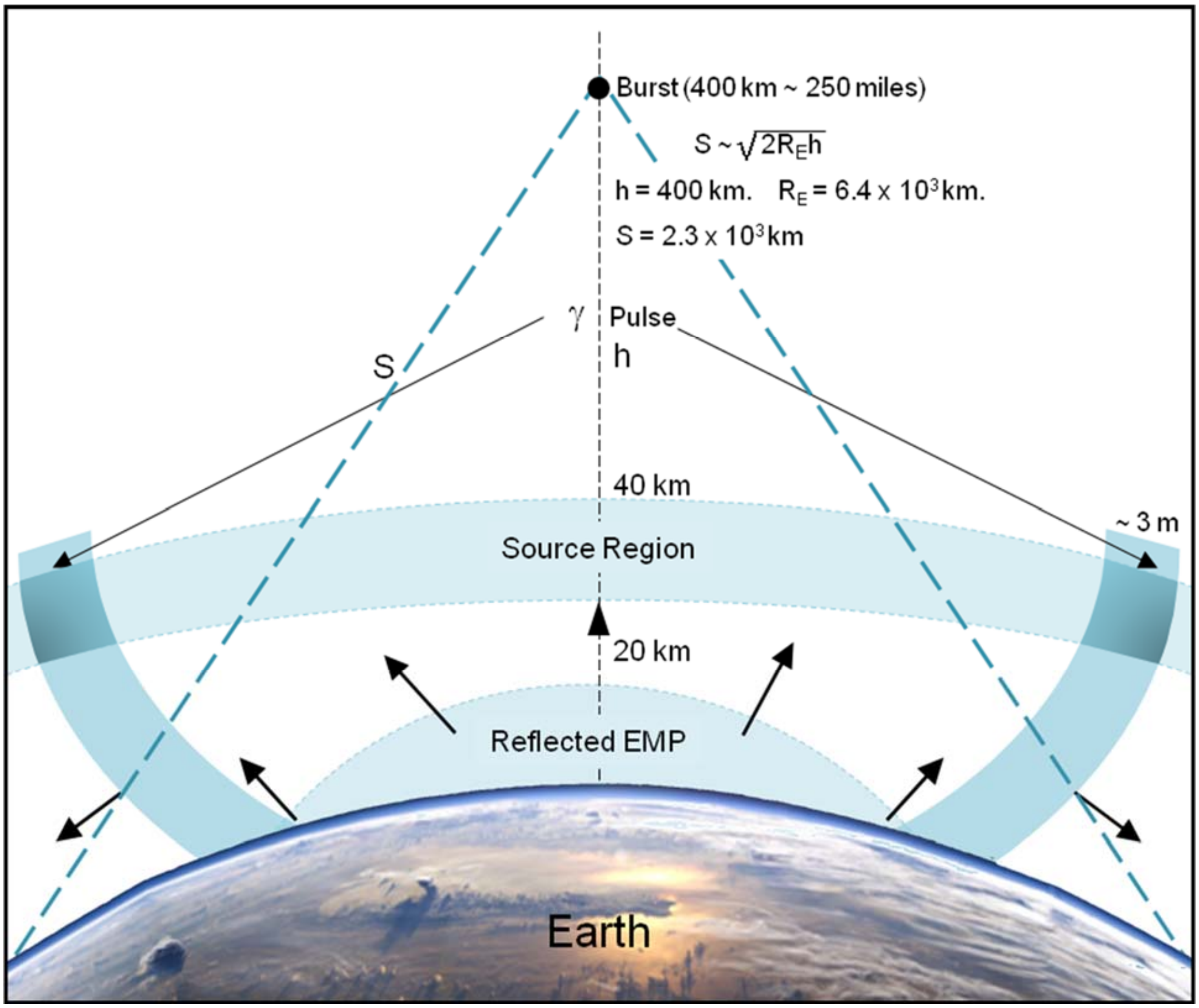

Figure A-4. Detailed geometry for Exo-Atmospheric burst.

A.5 The waveform and frequency content of HEMP is drastically different from its SREMP counterpart. This electron radiated energy creates a large, diverse E-Field in the range of tens of kilovolts/meter and an associated H-Field in the range of 10 to 100 ampere-turns/meter. Ninety percent of its energy is contained in the 100 kHz to 10 MHz range. See Figure A-5 for an example of the HEMP waveform, and Figure A-6 for relative energy versus frequency for an Exo-Atmospheric burst.

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

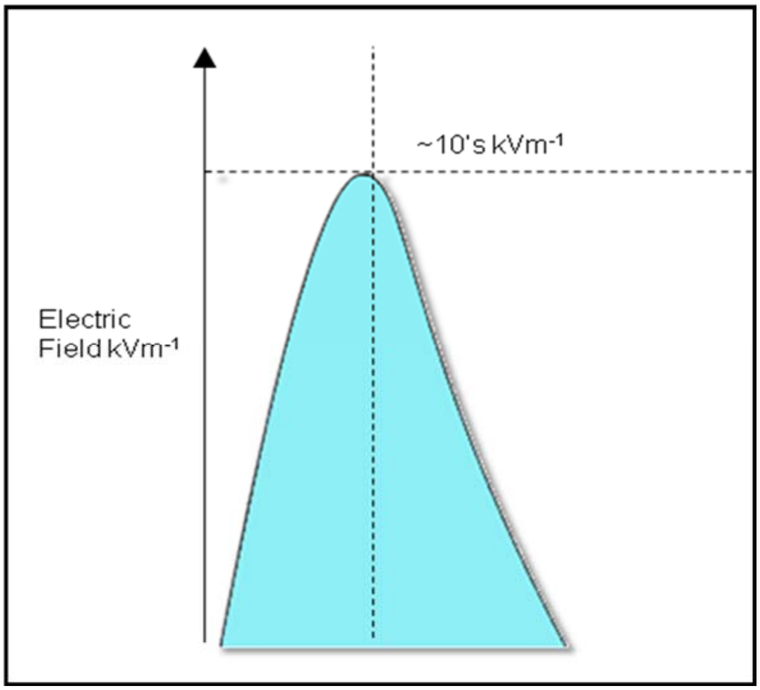

Figure A-5. Exo-Atmospheric EMP waveform.

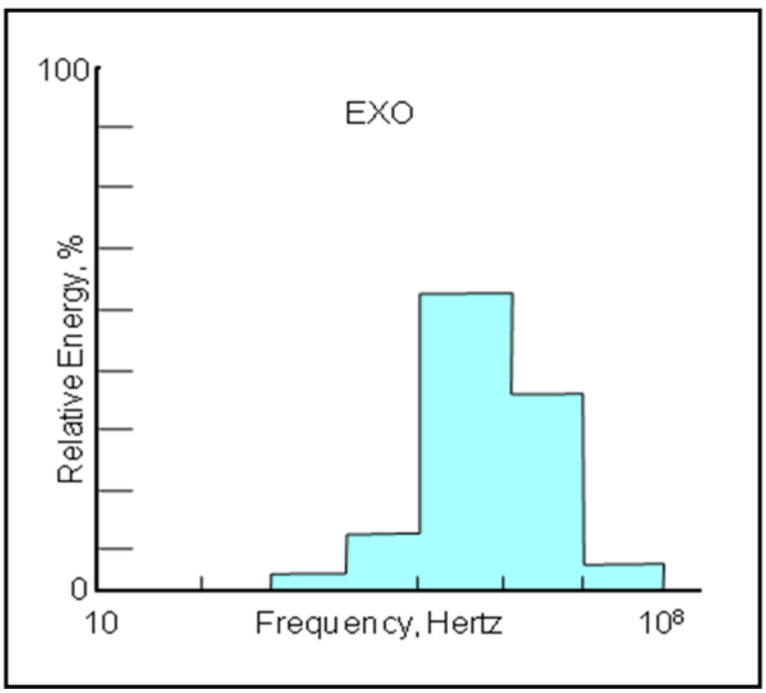

Figure A-6. Exo-Atmospheric relative energy versus frequency.

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

A.6 See Figure A-7 for an example of the diverse coverage in area and corresponding general E-Field contours by an Exo-Atmospheric burst.

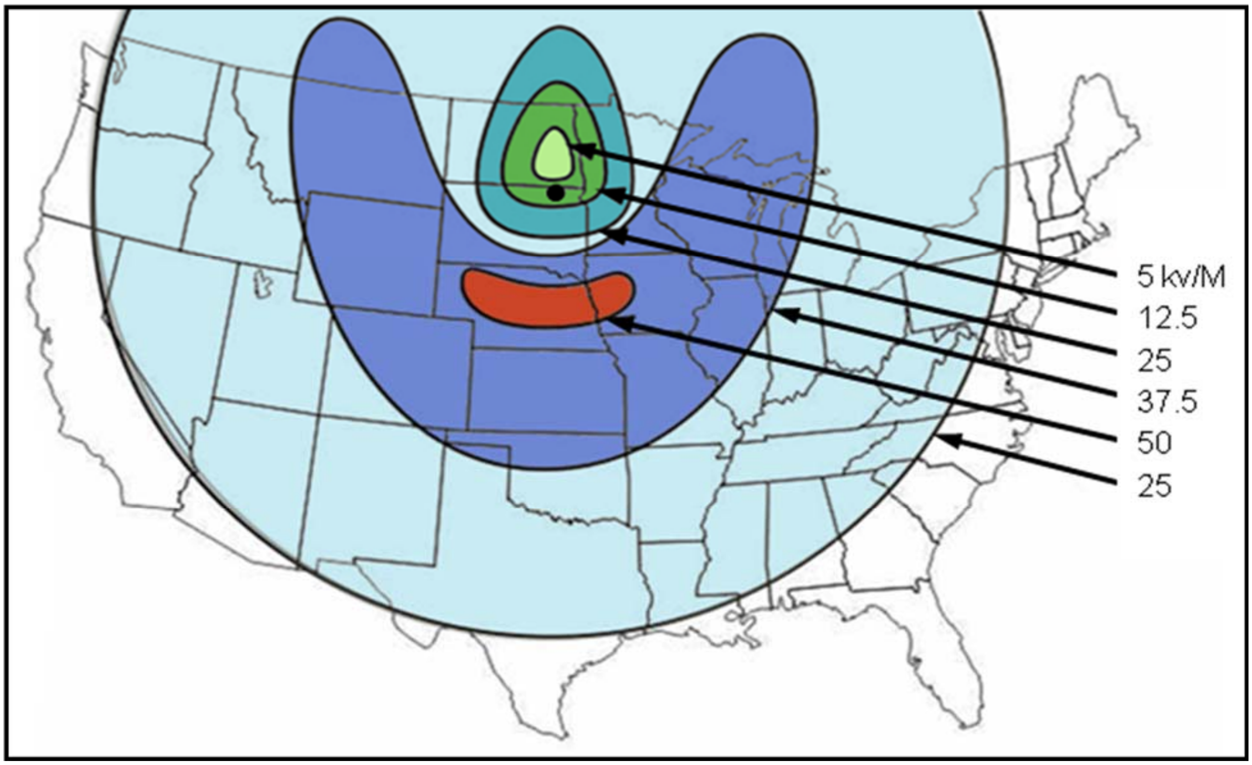

Figure A-7. Generated E-Field contours at the Earth's surface from a HEMP.

A.7 EMP testing requires the use of both experimental and analytical techniques to determine the response of systems and components to the EMP. Adequate testing of a system requires simulation of the EMP environment in terms of amplitude, time and geometrical effects of the entire system under study. Detonation altitude, angles of arrival and polarization of the field must be considered. Frequency domain calculations may be applied to determine critical resonant frequencies inherent to the test system. Current injection techniques must be utilized for distributed systems as an integral part of the EMP test. Current injection is greatly beneficial in the context of determining safety margins and enhancing and verifying HEMP simulator results. But, current injection should not be the primary means of obtaining accurate HEMP data.

A.8 Also, deliberate hardening devices like terminal protection devices must be analyzed, tested if necessary, to determine safety margins. Likewise, the attenuation afforded by enclosures must be analyzed so that its effects on the survivability of the enclosed electronics can be quantified.

APPENDIX A. ELECTROMAGNETIC ENVIRONMENT AND EFFECTS.

A.9 A safety briefing must be given to all personnel prior to testing and the test area must be cleared of all personnel before system operation. In order to avoid electric shock or burns, personnel shall refer to the system test plan for guidance on protecting personnel and equipment.

APPENDIX B. SAMPLE DETAILED TEST PLAN.

Draft Version

Project No. XXXX-XXX-XXXX

DETAILED TEST PLAN

FOR THE

HIGH ALTITUDE ELECTROMAGNETIC PULSE (HEMP)

QUALIFICATION TEST

OF THE

SYSTEM UNDER TEST (SUT) (*EXAMPLE*)

SURVIVABILITY, VULNERABILITY, & ASSESSMENT DIRECTORATE (SVAD)
GUSTAVO SIERRA
U.S. ARMY WHITE SANDS MISSILE RANGE
WSMR, NEW MEXICO 88002

DATE

Prepared for:

Project Manager / Project Office
ATTN: XXXX

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APPENDIX B. SAMPLE DETAILED TEST PLAN.

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APPENDIX B. SAMPLE DETAILED TEST PLAN.

TABLE OF CONTENTS

APPENDIX B. SAMPLE DETAILED TEST PLAN.

SECTION 1. INTRODUCTION

1.1 TEST OBJECTIVE

Determine the ability of the test article to survive exposure to the High Altitude Electromagnetic Pulse (HEMP) environment.

1.2 TEST CONCEPT

The HEMP Test is a qualification test of the test article. The test will be conducted at the Horizontally Polarized Dipole (HPD) Test Facility at White Sands Missile Range, New Mexico. The duration of the test is estimated to be one week. Only the E1 component of the HEMP waveform will be simulated.

In addition to qualifying the test article, the test results will be used to update the life cycle nuclear survivability database, document environmental test conditions, and define the system configuration.

1.3 SYSTEM DESCRIPTION

1.4 UNIQUE PERSONNEL REQUIREMENTS

Qualified personnel will perform test article operation and maintenance. The SUT team will be comprised of Test Center personnel that are responsible for the overall test execution, system operation, system monitoring, and data analysis. SUT personnel will also assist the Program Manager Representatives in understanding any specific results/analysis of the HEMP test. The SUT personnel may be comprised of Test Officers, Analysts, Data Collectors, Drivers, Artillery Testers, Communication Techs, etc. The HPD personnel are responsible for operating the HPD facility, instrumentation, and data collection.

SECTION 2. HEMP TEST

2.1 OBJECTIVE

Determine the ability of the test article to survive exposure to the High Altitude Electromagnetic Pulse (HEMP) environment.

2.2 CRITERIA

The test article will operate after being exposed to the E1component of HEMP waveform as specified in MIL-STD-2169C. (To maintain the unclassified status of this test plan, the specific parameters are not given in this document).

2.2.1 The test article will be considered to have survived exposure to the HEMP environment if it is exposed to HEMP while powered up and operating, and it operates through and continues to operate after the exposure.

2.2.2 The test article will be considered to have survived exposure to the HEMP environment if it is exposed to HEMP while powered up and operating and can be made fully operational using reset or power up procedures requiring no maintenance or replacement of parts.

APPENDIX B. SAMPLE DETAILED TEST PLAN.

2.3 TEST PROCEDURES

2.3.1 PRIOR TO TEST

2.3.1.1 HPD operations personnel will determine and verify the points in the test volume that yield 50% and 100% of the required HEMP environment using E-Field and H-Field sensors and repeated firings of the HPD pulser.

2.3.1.2 SUT personnel will assemble the test article and verify that it operates properly in both the Ground Mount and high mobility multi-purpose wheeled vehicle (HMMWV) Mount configurations. SUT personnel are Test Center personnel that are responsible for the overall test execution, system operation, system monitoring, and data analysis. SUT personnel will also assist the Program Manager Representatives in understanding any specific results/analysis of the HEMP test.

2.3.2 DURING TEST

2.3.2.1 SUT personnel will configure the test article for Ground Mount and position the test article such that its center is at the point in the test volume that yields 50% of the required HEMP criteria.

2.3.2.2 HPD operations personnel will position the field sensors at a position in the test volume to allow confirmation on a pulse-to-pulse basis that the proper amplitude of the test field is being produced.

2.3.2.3 HPD operations personnel will also place current probes for data collection, data analysis. The current probes will each be connected by coaxial cable to Nanofast units. The Nanofast units will each be connected by fiber optic cables to digitizers housed in the HPD Control Van. The digitizers will be controlled by a computer. All instrumentation will be verified to be operating properly.

2.3.2.4 The test article will be positioned such that the front is oriented toward the HPD.

2.3.2.5 The test article will be verified to be operating properly.

2.3.2.6 All personnel will be directed to a safe area.

2.3.2.7 The HPD personnel will fire the pulser and confirm that the proper field level was generated. HPD personnel will process the current curves captured from the current probes and confirm that acceptable plots have been stored. SUT personnel will verify that the test article has operated through and/or survived the exposure. Exposures will be repeated until the test field achieves the appropriate amplitude, current plots are acceptable, and test article operation/survival is verified.

2.3.2.8 The test article will be rotated clockwise by 90 degrees and the process repeated until illuminations required for data acquisition have been achieved.

2.3.2.9 SUT personnel will configure the test article for Ground Mount and position the test article such that its center is at the point in the test volume that yields 100% of the required HEMP criteria and the procedures described in paragraphs 2.3.2.4 through 2.3.2.8 repeated until all four sides have been exposed to 100% and 120% of criteria and all data collected.

APPENDIX B. SAMPLE DETAILED TEST PLAN.

2.3.2.10 SUT personnel will configure the test article for HMMWV Mount and position the test article such that its center is at the point in the test volume that yields 50% of the required HEMP criteria and the process described in paragraphs 2.3.2.4 through 2.3.2.8 repeated.

2.3.2.11 SUT personnel will position the HMMWV Mount configured test article such that its center is at the point in the test volume that yields 100% and 120% of the required HEMP criteria and the procedures described in paragraphs 2.3.2.2 through 2.3.2.8 will be repeated until all four sides of the HMMWV Mount test article have been exposed to 100% and 120% of criteria and all data collected.

2.3.2.12 When all required data have been collected after illumination to 50%, 100% and 120% of criteria in both Ground Mount and HMMWV Mount configurations, and all data is recorded, the test will be complete.

2.3.2.13 If the test article becomes inoperable during the test, on-site test personnel will discuss the situation and determine whether to repair the test article and continue the test or to terminate the test.

2.3.2.14 If during the test a situation arises that requires a departure from or alteration to the procedures specified in this plan, the situation will be discussed and alternate procedures agreed to and documented by on-site Test Center personnel.

2.4 DATA REQUIRED

2.4.1 Test engineer logs with Test Shot Number, Facility Shot Number, Date, Time, test article Configuration (i.e. Ground Mount or HMMWV Mount), test article Orientation (Front, Road Side, Rear, Curb Side), Percent of Criteria (50% or 100%), and Comments. Comments will contain a description of the operating condition of the test article or procedures taken to return to an operable condition.

2.4.2 At least one set each of the amplitude versus time plots or data of the calibration shots made at the 50%, 100% and 120% criteria test locations.

2.4.3 Amplitude versus time plots or data of the current measured by the current probes for each test article configuration, criteria level (50, 100% or 120%), and test article orientation.

2.4.4 Diagrams or photographs of the test item and test area.

2.5 DATA ANALYSIS/PROCEDURE

The criteria will be met if the test article operates and/or survives 100% of the HEMP field in all specified orientations and configurations.

END OF SAMPLE TEST PLAN.

APPENDIX C. DATA TABLES AND DOCUMENTATION.

TABLE C-1. TESTING DOCUMENTATION EXAMPLE

TEST CONDUCTOR: XXXXXXX DATE: 20 May 09
FACILITY: HEMP Facility PAGE_1__ OF _10_

Shot # and Item #	Utilized Equipment Serial #s	Test Level kV/m	Test Orientation	Test Mode	Pretest and Post-test Results	Test Points and Comments
1 # 5723	GENERIC MISSILE S/N# 26264 *Test Setup #1*	1st	Tank Parallel to E-Field Distance = 15 Meters GCVP of Tank	Powered and Operational Hull = Turret - 0°	pre - OK post – OK	11 8-Input Multiple Links. – See Test Point Information
2 #5724	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
3 # 5725	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
4 # 5726	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
5 # 5727	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
6 # 5728	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above
7 # 5729	Same as 1 Above	1st	Same as 1 Above	Same as 1 Above	pre - OK post – OK	Same as 1 Above

General Comments: E-Field = Electric Field

APPENDIX C. DATA TABLES AND DOCUMENTATION.

TABLE C-2. SAMPLE HEMP TEST POINT – CURRENT PROBE INFORMATION

Link Name	LINK S/N	Input #	Test Point ID	Test Point Description
Alpha	312	0	DID1	DID J1
Alpha	312	1	DID2	DID J2
Alpha	312	2	DID3	DID J3
Alpha	312	3	HMP1	HMPU J1
Alpha	312	4	HMP7	HMPU J7
Alpha	312	5	HMP8	HMPU J8
Alpha	312	6	HMP9	HMPU J9
Alpha	312	7	HMPX	HMPU J10
Bravo	423	0	HPDE	HPDU J14
Bravo	423	1	HPDB	HPDU J11
Bravo	423	2	HPD1	HPDU J1
Bravo	423	3	HPD8	HPDU J8
Bravo	423	4	HPD7	HPDU J7
Bravo	423	5	HPDD	HPDU J13
Bravo	423	6	HPDC	HPDU J12
Bravo	423	7	HPDA	HPDU J10
Charlie	133	0	HPD9	HPDU J9
Charlie	133	1	HPD6	HPDU J6
Charlie	133	2	HPD5	HPDU J5
Charlie	133	3	HPD4	HPDU J4
Charlie	133	4	FEA2	FEA J2
Charlie	133	5	TCU1	TCU J1
Charlie	133	6	DEC3	DECU J3
Charlie	133	7	DEC5	DECU J5
Delta	101	0	AIM6	AIM J6
Delta	101	1	AIM7	AIM J7
Delta	101	2	AIM1	AIM J1
Delta	101	3	AIM2	AIM J2
Delta	101	4	AIM3	AIM J3
Delta	101	5	AIM5	AIM J5
Delta	101	6	RS21	RSM2 J1
Delta	101	7	RS22	RSM2 J2

APPENDIX C. DATA TABLES AND DOCUMENTATION.

Figure C-1. Generic missile launcher HEMP test setup.

APPENDIX C. DATA TABLES AND DOCUMENTATION.

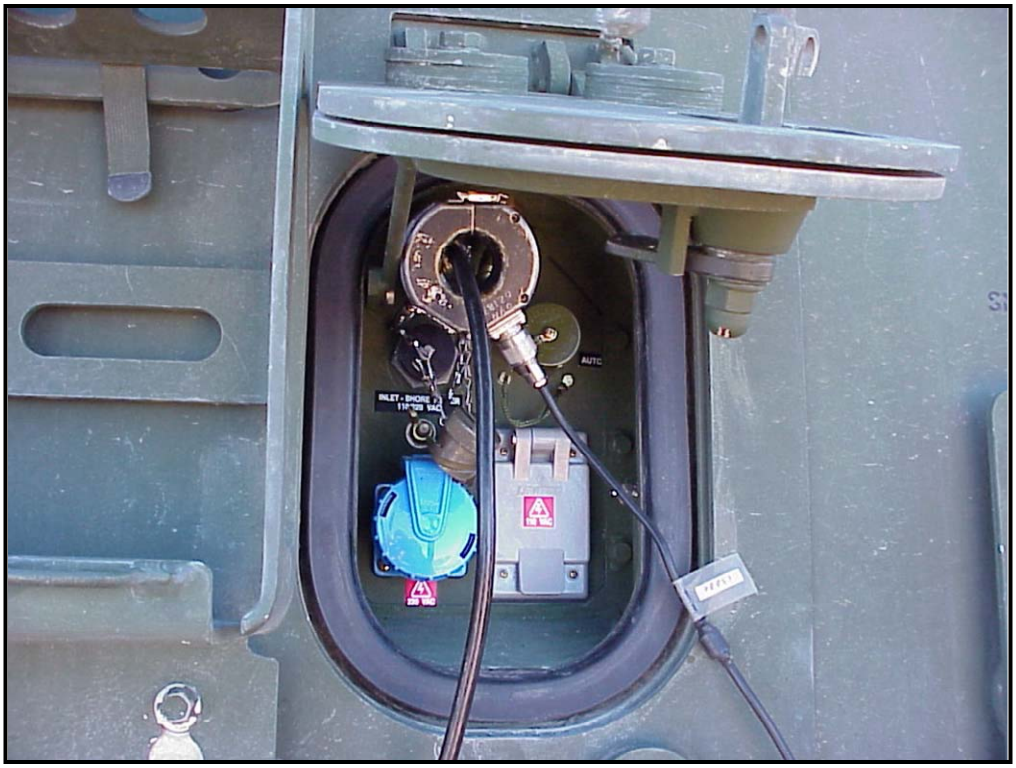

Figure C-2. Sample probe-instrumentation HEMP test setup.

APPENDIX C. DATA TABLES AND DOCUMENTATION.

TABLE C-3. SAMPLE CURRENT TEST POINT REDUCED DATA

Test ID	Orientation	Shot#	Peak I	Res Freq	Low Freq	High Freq	Bandwidth	Q
CEU1	parallel-1-turret-front	5723	-0.72343	2.37E+07	2.33E+07	2.59E+07	2.54E+06	9.3128
RSC1	parallel-1-turret-front	5723	-0.78004	2.37E+07	2.34E+07	2.58E+07	2.40E+06	9.86972
AIM6	parallel-1-turret-front	5724	0.254524	1.52E+07	1.40E+07	1.62E+07	2.20E+06	6.90684
CDU1	parallel-1-turret-front	5724	0.854443	2.54E+07	2.17E+07	2.60E+07	4.36E+06	5.84013
CIT1	parallel-1-turret-front	5724	-0.87288	2.32E+07	2.25E+07	2.38E+07	1.29E+06	17.9898
DID1	parallel-1-turret-front	5724	-0.21612	3.15E+07	3.02E+07	3.21E+07	1.93E+06	16.3001
GCD4	parallel-1-turret-front	5724	0.879601	2.30E+07	2.18E+07	2.34E+07	1.58E+06	14.5688
HPD9	parallel-1-turret-front	5724	-0.26658	4.33E+07	4.26E+07	4.51E+07	2.51E+06	17.2656
HPDE	parallel-1-turret-front	5724	0.221622	3.17E+07	3.06E+07	3.22E+07	1.58E+06	20.1163
AIM7	parallel-1-turret-front	5725	-0.22246	1.19E+07	1.14E+07	1.22E+07	863666	13.7974
DID2	parallel-1-turret-front	5725	-0.15849	4.51E+07	4.43E+07	4.62E+07	1.93E+06	23.4194
HPD6	parallel-1-turret-front	5725	-0.43752	5.16E+07	5.02E+07	5.23E+07	2.12E+06	24.2788
HPDB	parallel-1-turret-front	5725	-0.18246	2.27E+07	2.19E+07	2.37E+07	1.84E+06	12.3403
MMU1	parallel-1-turret-front	5725	0.046358	2.37E+07	2.28E+07	2.59E+07	3.11E+06	7.63901
RSC4	parallel-1-turret-front	5725	0.72278	3.38E+07	3.29E+07	3.43E+07	1.42E+06	23.7429
AIM1	parallel-1-turret-front	5726	0.216101	4.89E+07	4.76E+07	4.97E+07	2.10E+06	23.3346
CDU2	parallel-1-turret-front	5726	1.65474	2.38E+07	2.29E+07	2.48E+07	1.96E+06	12.1048
CEU3	parallel-1-turret-front	5726	-7.05391	2.59E+07	2.53E+07	2.69E+07	1.68E+06	15.3943
DID3	parallel-1-turret-front	5726	0.235663	4.56E+07	4.44E+07	4.66E+07	2.25E+06	20.2586
FCE4	parallel-1-turret-front	5726	2.53957	2.39E+07	2.27E+07	2.48E+07	2.15E+06	11.1238

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APPENDIX D. HPD II E-FIELD PROPAGATION CHARACTERISTICS.

D.1 To further understand the mobile HEMP facility at SVAD, a map of the electric field will be included as well as wave forms of the pulses below. The diagram in Figure D-1 displays an overview of the test area and the electric-field (V/m). The mapping data shows the electric field on the HPD II test pad and also a point 43 meters away from the edge of the pad. The colored diagram shows the E-Field propagating.

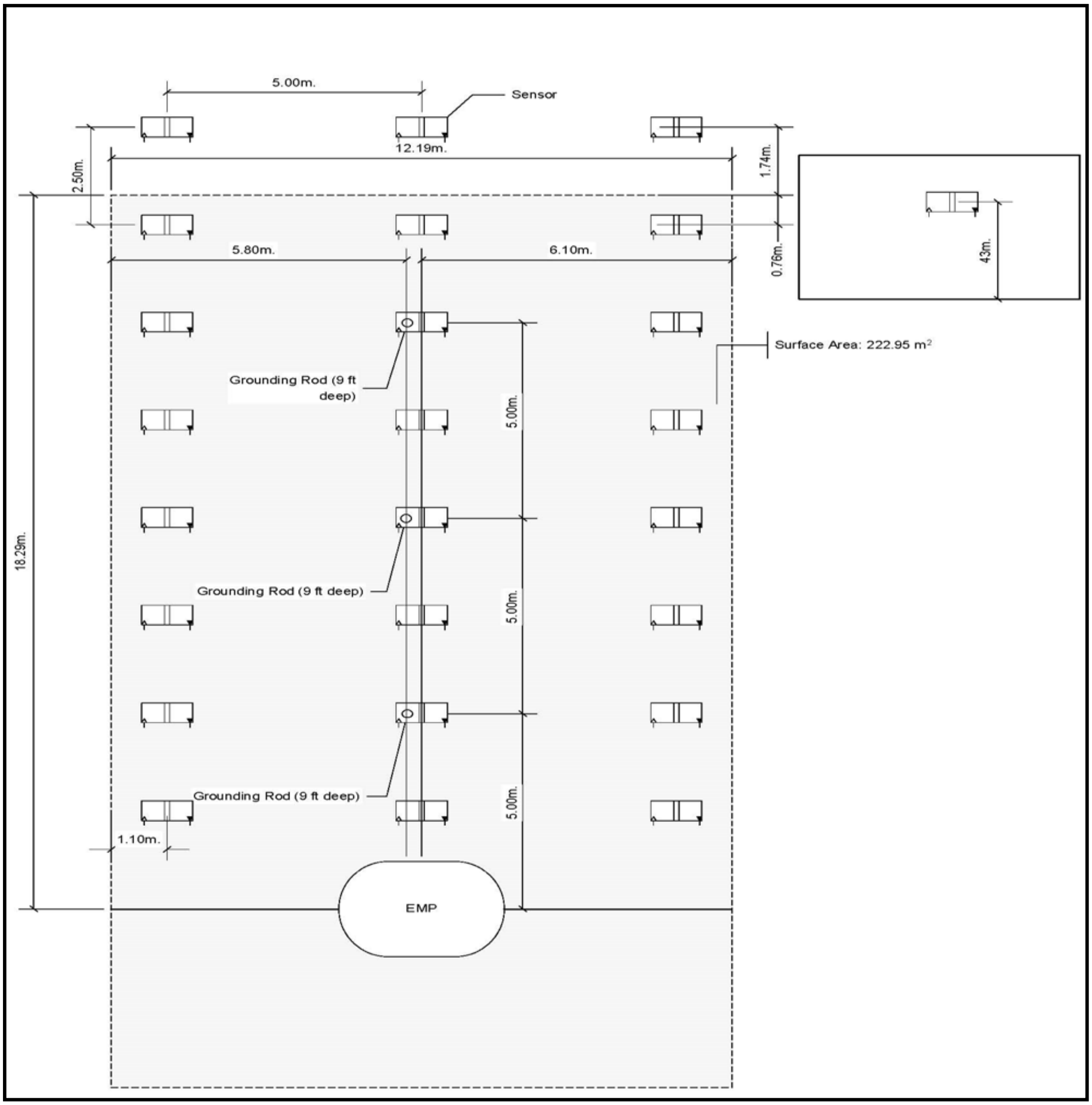


Figure D-1. HPD II HEMP test area topside overview.

APPENDIX D. HPD II E-FIELD PROPAGATION CHARACTERISTICS.

D.2 A field map of the electric field was measured, the waveforms were identified and the peak fields were recorded and placed in a database for processing of data and/or conversions. The resulting Figures D-2 and D-3 display the electric field propagation. The equipment used for this test included Nanofast and Optical Data System (ODS) transmitters, probes, and baluns. A transmitter, probe, and balun are placed at a point on the map to measure the field strength at that point. Then data collection points are moved to another point. This is repeated until all the desired points are measured.

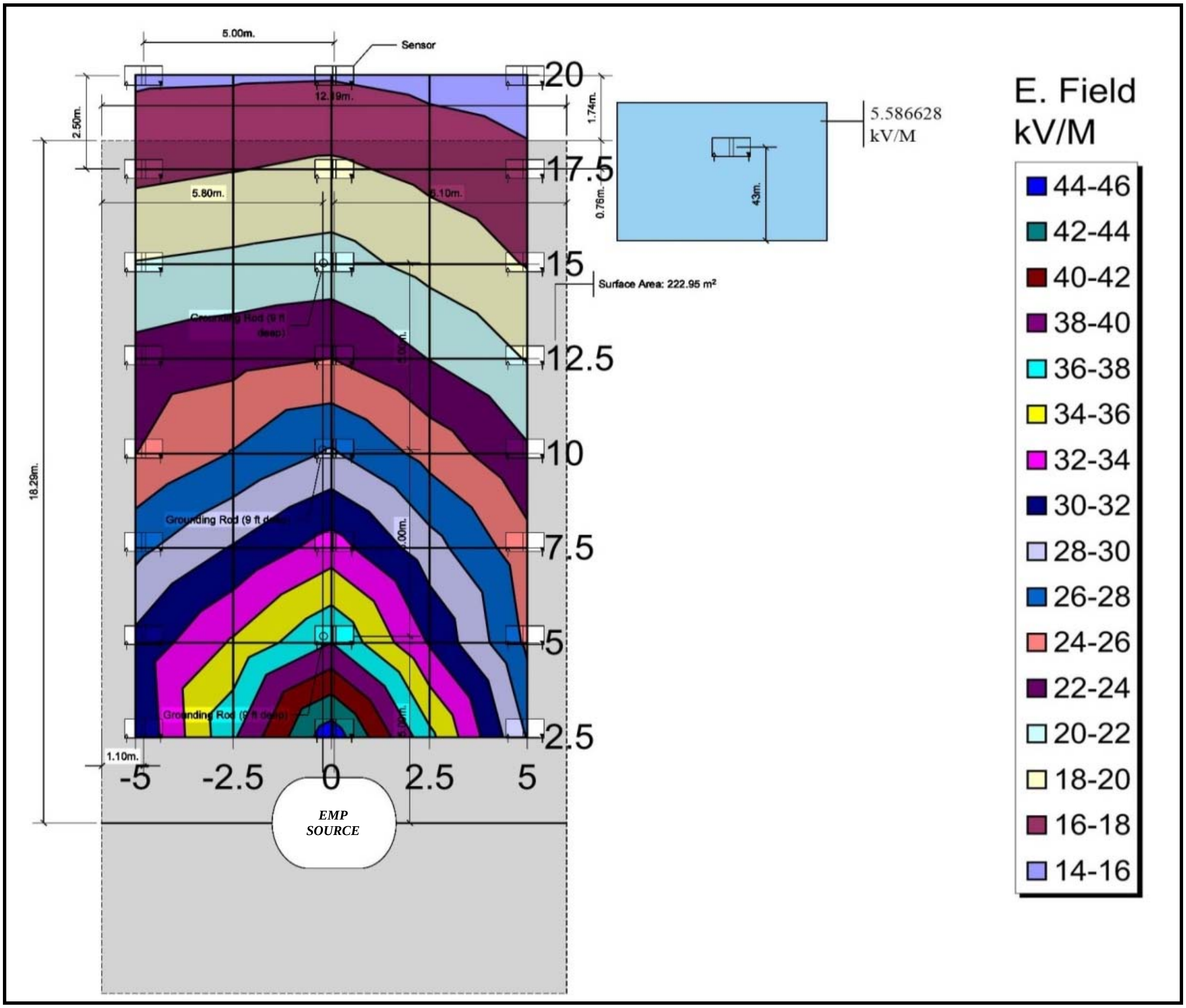
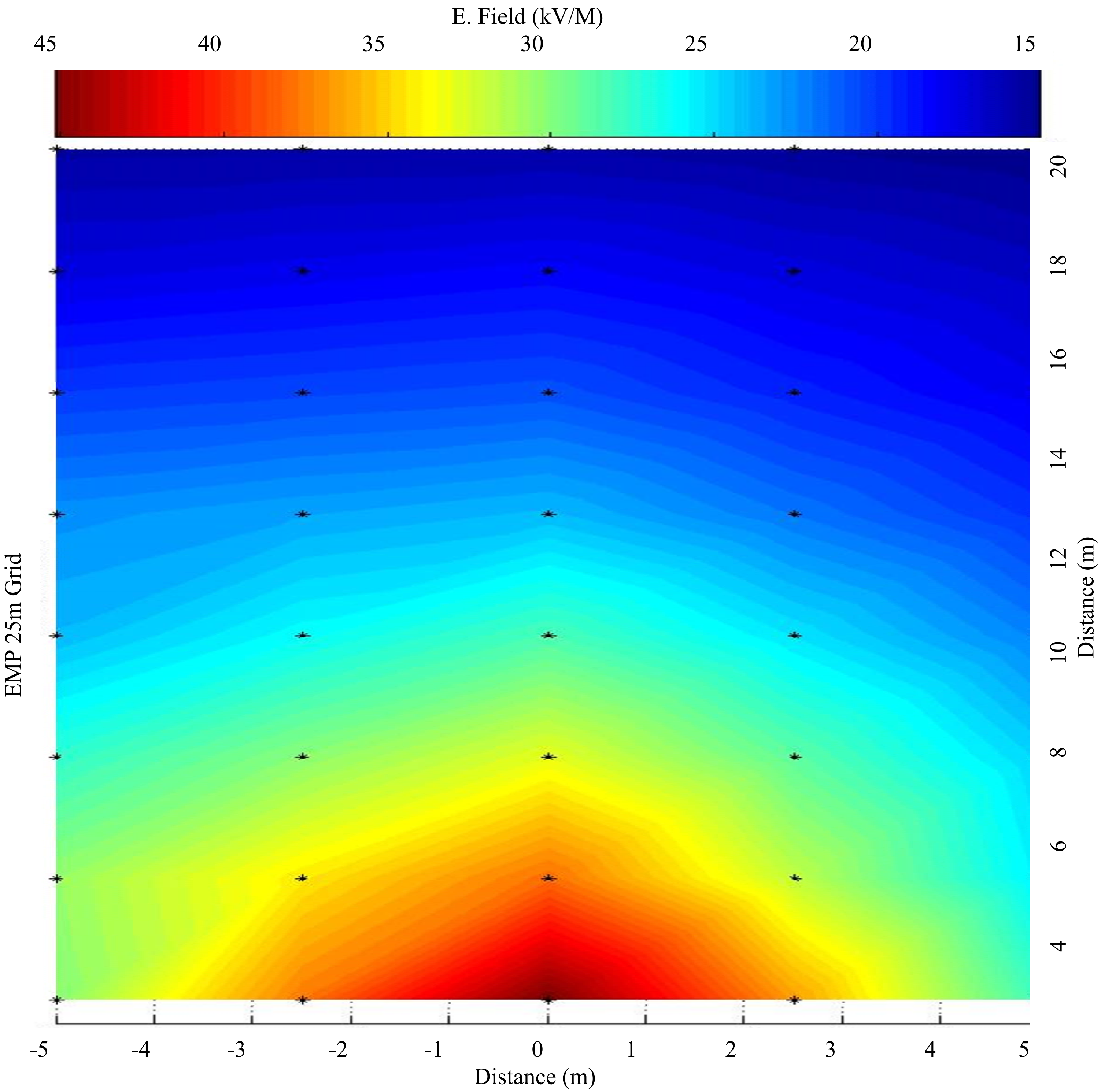


Figure D-2. Topside overview of HPD II EMP source E-Field map with data points.

APPENDIX D. HPD II E-FIELD PROPAGATION CHARACTERISTICS.



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APPENDIX E. AFEMP E-FIELD PROPAGATION CHARACTERISTICS.

E.1 The diagram in Figure E-1 displays an overview of the AFEMP test area and the location of the test points throughout the test pad.

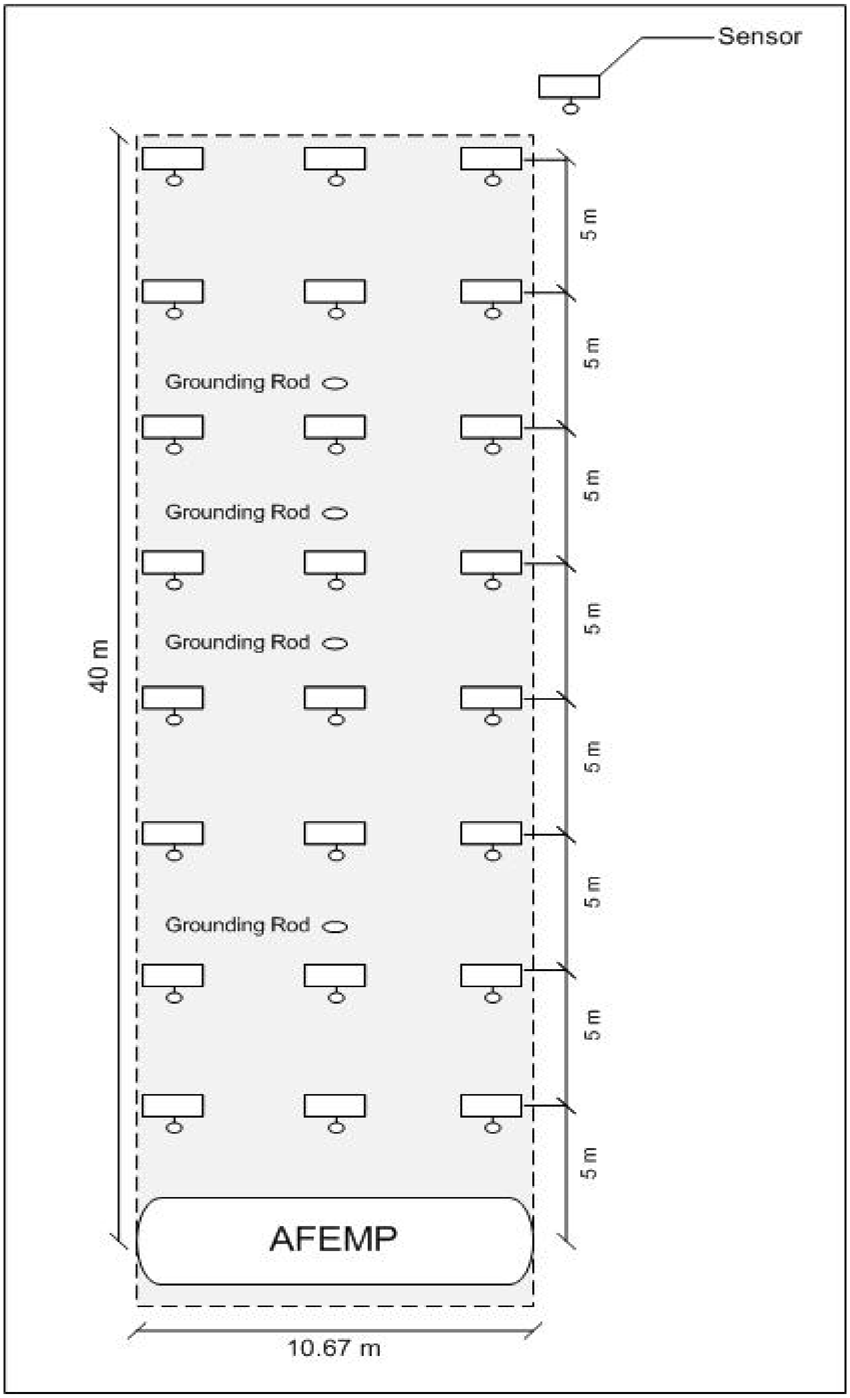

Figure E-1. AFEMP test area topside overview.

APPENDIX E. AFEMP E-FIELD PROPAGATION CHARACTERISTICS.

E.2 Figure E-2 displays the electric field propagation measured at the AFEMP facility. The measured peak fields were recorded and placed in a database for processing of data and/or conversions. The equipment used for this test included optical data transmitters, optical data receivers, probes and baluns. A transmitter, probe, and balun are placed at a point on the map to measure the field strength at that point. Then data collection points are moved to another point. This is repeated until all the desired points are measured.

APPENDIX E. AFEMP E-FIELD PROPAGATION CHARACTERISTICS.

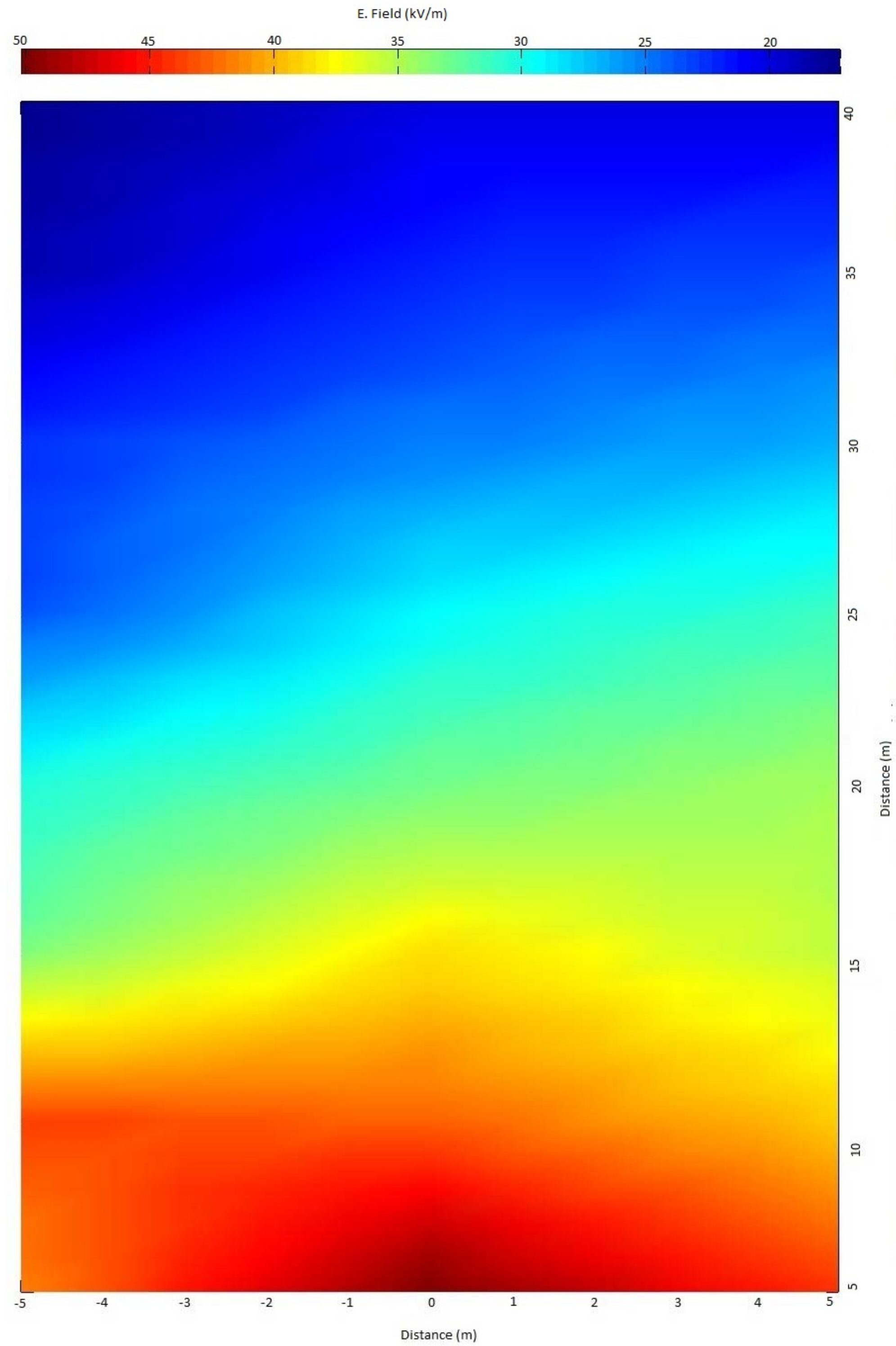

Figure E-2. EMP source topside overview AFEMP E-Field propagation.

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APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

Provided is an overview of the data processing that occurs in HEMP testing to form a basic knowledge foundation. It should be noted that this is not an in-depth presentation and that the procedures used and data accuracy provided by the instrumentation are in general the responsibility of the test facility.

F.1 DATA MEASUREMENTS.

a. For testing at pulse/high frequency facilities most sensors and data links are self-calibrated by the instrumentation specialist. The traceability back to a laboratory calibration is through the use of a network analyzer which has calibration performed at the factory or a standard calibration laboratory.

b. Sensors. In general the facility calibration of sensors is limited to the ones which measure voltage or current; sensors for measuring fields (electric or magnetic) or for measuring surface currents are factory calibrated. The current probes are available with different current measuring capabilities and different through hole sizes, in most cases (except for very small very specific probes) clamp on devices are used. A special adapter is required for each size probe for the facility calibration to be performed. The probe adapter (see Figure F-1) allows for the placement of the probe around the center conductor and inside the external conductor. The probe is then connected to a network analyzer. The network analyzer output feeds both the forcing function and the reference measurement and measures the voltage output of the current probe. This forcing function is driven across the frequency spectrum for which the current probe is being calibrated. The current probe voltage output is divided by the current through the fixture; the current through the fixture is based on the measured reference voltage and the fixed load impedance. The result is the transfer function of the current probe versus frequency which is called the probe transfer impedance since the units are volts/ampere. The voltage probes are calibrated in the same manner with the exception that the transfer function units are volts/volt. Experience has indicated that 400 measurements across the frequency spectrum tend to be adequate for calibration. This frequency calibration is used as follows: the data produced by the current or voltage probe are recorded on fast oscilloscopes as voltages in the time domain. The recorded data then requires correction for the probe transfer function (frequency response) and conversion to the correct units of measure. This is accomplished using convolution in the time domain, the process however takes place in the frequency domain since in the frequency domain convolution reduces to simple point by point division. The process for a current probe is that the recorded time domain waveform is converted to the frequency domain using FFT. The resulting frequency data are then divided on a per frequency basis by the probe transfer function at that frequency, interpolation between probe calibration frequency points is used to match the exact frequency resulting from the FFT. Once the convolution has taken place the FFT is now corrected for probe response and the inverse FFT results in the corrected time response with the appropriate units.

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

Figure F-1. Probe adapter.

F.2 FIBER OPTIC DATA LINKS.

In general the facility calibration of data links is performed as matching pairs (i.e. the optical transmitter and the optical receiver are matched into a data link), these matched pairs are always used together during data acquisition. The DATA links are available from several manufactures one of the most common is NANO-FAST / EG&G ODS-1500. The link is connected to a network analyzer. The network analyzer output feeds both the forcing function and the reference measurement and measures the voltage output of the link. This forcing function is driven across the frequency spectrum for which the link is being calibrated. The link voltage output is divided by the measured reference voltage across the frequency range being calibrated. The result is the transfer function of the link versus frequency for which the units are volts/volt. Experience has indicated that 400 measurements across the frequency spectrum tend to be adequate for calibration. This frequency calibration is used as follows: the data produced by the sensor are input to the fiber transmitter and received by the fiber receiver and the receiver output voltage is recorded on fast oscilloscopes as voltages in the time domain. The recorded data then requires correction for the link transfer function (frequency response). This is accomplished using convolution in the time domain, the process however takes place in the frequency domain since in the frequency domain convolution reduces to simple point by point division. The process for a link is that the recorded time domain waveform is converted to the frequency domain using FFT. The resulting frequency data are then divided on a per frequency basis by the link transfer function at that frequency, interpolation between probe calibration frequency points is used to match the exact frequency resulting from the FFT. Once the convolution has taken place the FFT is now corrected for the link response and the inverse FFT results in the corrected time response.

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION
AND MATHEMATICS.

F.3 FIBER.

The fiber is not calibrated versus frequency since it possesses no elements which would result in a change in frequency spectrum transmission. Most fiber links provide for a standard signal being transmitted over the fiber to verify its acceptability. This measurement being unacceptable indicates two potential faults; the first is that the ends of the fiber are dirty and the second is that the fiber is broken.

F.4 DEMONSTRATION OF MEASUREMENT CONVERSION.

The data processing and calculations at pulsed/high frequency facilities are usually performed by the facility data specialist. Figure F-2 displays a block diagram illustrating the steps used to process data acquired during HEMP testing.

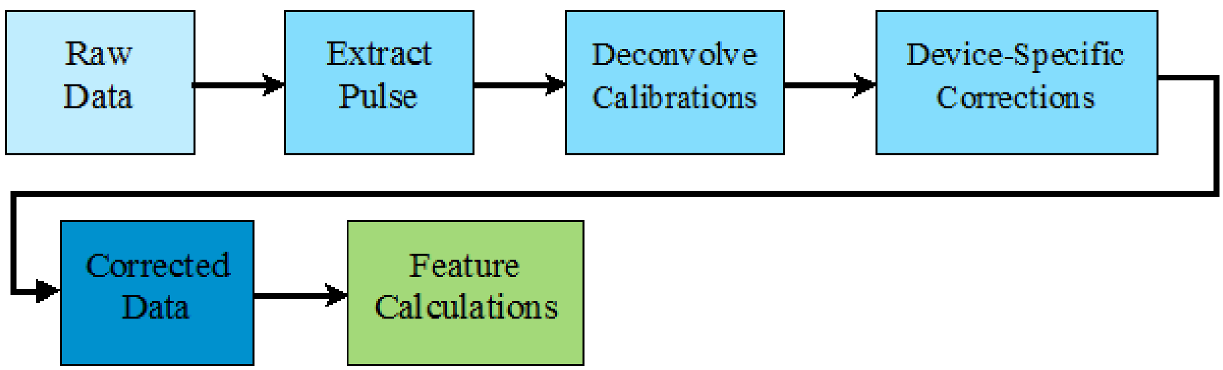

Figure F-2. Block diagram for data processing.

As indicated in paragraph F.1, the data starts as a raw voltage measurement recorded on a digitizing oscilloscope. This raw data are processed through frequency domain convolution using the instrumentation factors indicated in paragraph F.1 into the final corrected measurement. Figure F-3 shows graphically the dramatic changes that occur in the data as the units are converted and the frequency response of the instrumentation is accounted for.

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

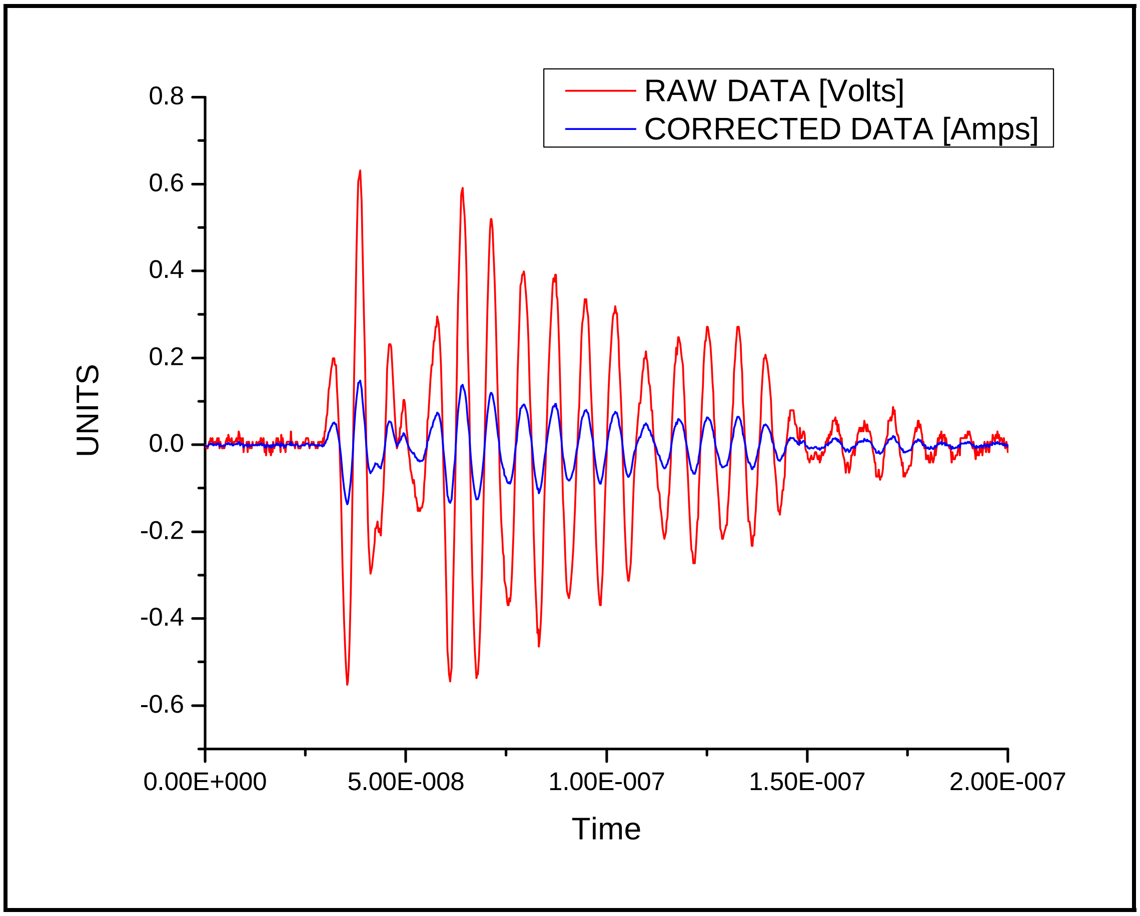

Figure F-3. Raw data correction.

F.5 DATA CALCULATIONS.

The purpose of the calculations is to develop a set of scalars or NORMS which can be used to describe the characteristics of the induced signals and provide engineering data for use in the correction of deficiencies if required. The acquired pulse is clipped to reduce the noise in the measurement or to remove any biasing from the signal. Figure F-4 illustrates a clipped pulse.

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

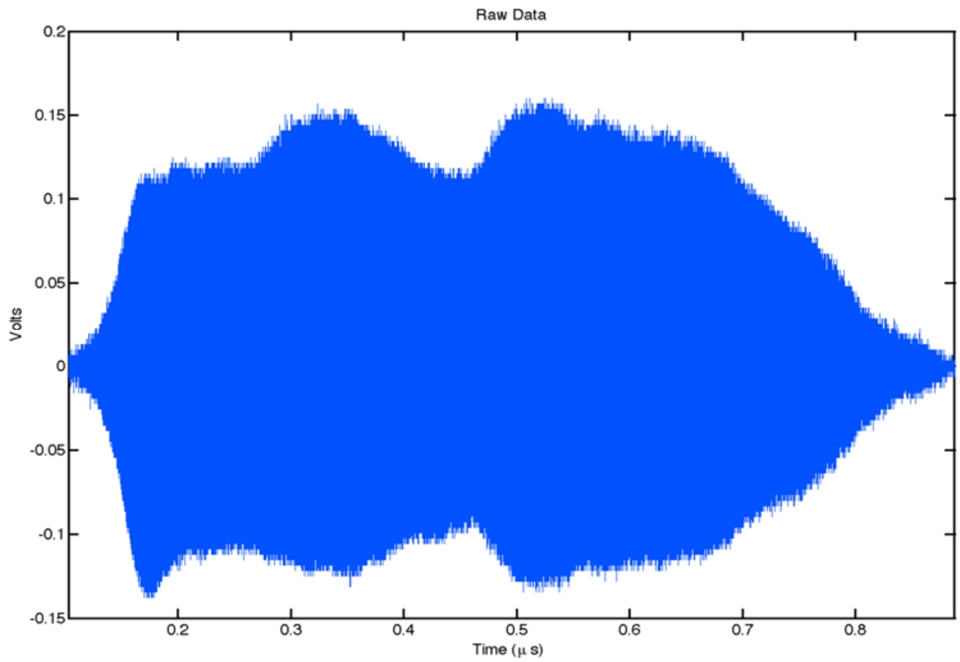

Figure F-4. Clipped pulse.

To remove the effects of the instrumentation from a signal the calibration data for the instrumentation is deconvolved from the signal. A signal represented as $x(t)$ is affected by a system $h(t)$ to produce an output $y(t)$ by the relationship:

$$y(t) = x(t) * h(t) = \int_{-\infty}^{t} x(\tau)h(t-\tau)d\tau,$$

the equation for convolution. Calculating the convolution integral in the time domain is an inefficient process therefore the same result may be obtained using the Convolution/Multiplication property for the Fourier Transform:

$$y(t) = x(t) * y(t) \Rightarrow Y(f) = X(f)H(f).$$

For a continuous time domain signal $x(t)$ the Continuous Fourier Transform is determined to be

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt.$$

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

A digitized signal $x[n]$ with a sampling period of Δt containing N samples can be approximated as:

$$X(f) = \sum_{n=0}^{N} x[n] e^{-t-j2\pi f n \Delta t} \Delta t.$$

Using the FFT algorithm $X(f)$ is calculated to be:

$$X(f) = FFT\{x[n]\} \cdot \Delta t.$$

The deconvolution process is illustrated in Figure F-5. Where $p[n]$ is the clipped pulse.

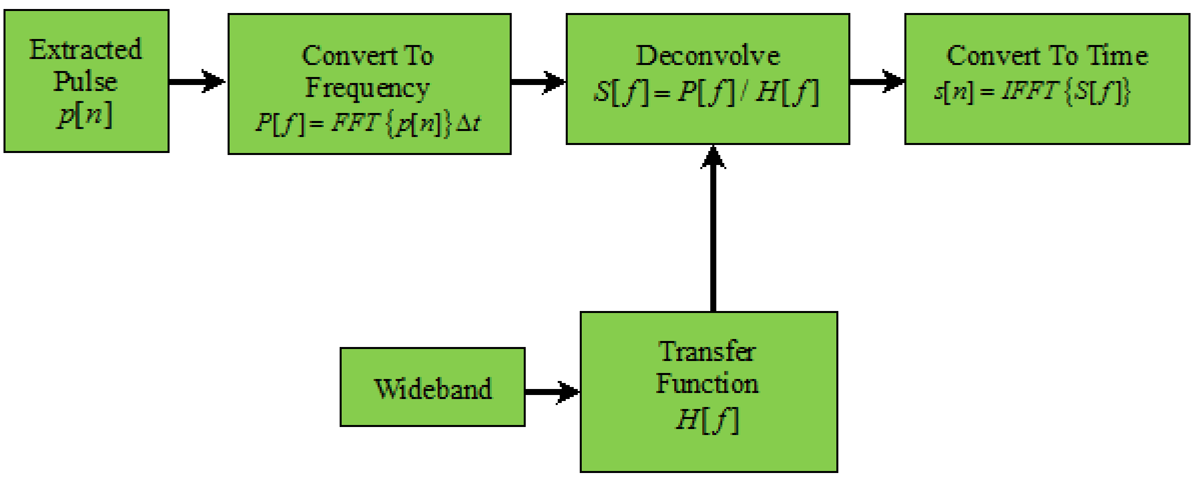

Figure F-5. Deconvolution process block diagram.

Data are processed using a wideband method which uses the calibration files in the data containing only magnitude and phase data for the transmission parameter S_{21} of the instrumentation. Figure F-6 illustrates the wideband method.

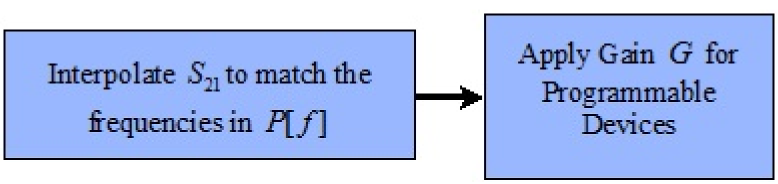

Figure F-6. Wideband processing block diagram.

For all instrumentation in the instrument chain of a measurement the S_{21} parameter is interpolated to match the frequency spacing of the pulse spectrum $P[f]$ which is $\Delta f = (\frac{F_S}{2})/N$, where $F_s = 1/\Delta t$ is the sampling rate of the digitized signal and N is the number of points in $P[f]$.

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

The magnitude of the calibration data can be interpolated by:

$$|S_{21}(f)| = |S_{21}(f_1)| + (|S_{21}(f_2)| - |S_{21}(f_1)|)\frac{f-f_1}{f_2-f_1}.$$

The phase of the calibration data can be interpolated by:

$$\angle S_{21}(f) = \angle S_{21}(f_1) + (\angle S_{21}(f_2) - \angle S_{21}(f_1))\frac{f-f_1}{f_2-f_1}.$$

The gain for any programmable devices is applied to the signal by using the following equation:

$$P(f) = P(f) \cdot 10^{-\frac{G_{dB}}{20}}.$$

Finally, the interpolated $S_{21}(f)$ parameter is used as the transfer function $H[f]$ for obtaining the corrected signal $S[f]$ from $P[f]$.

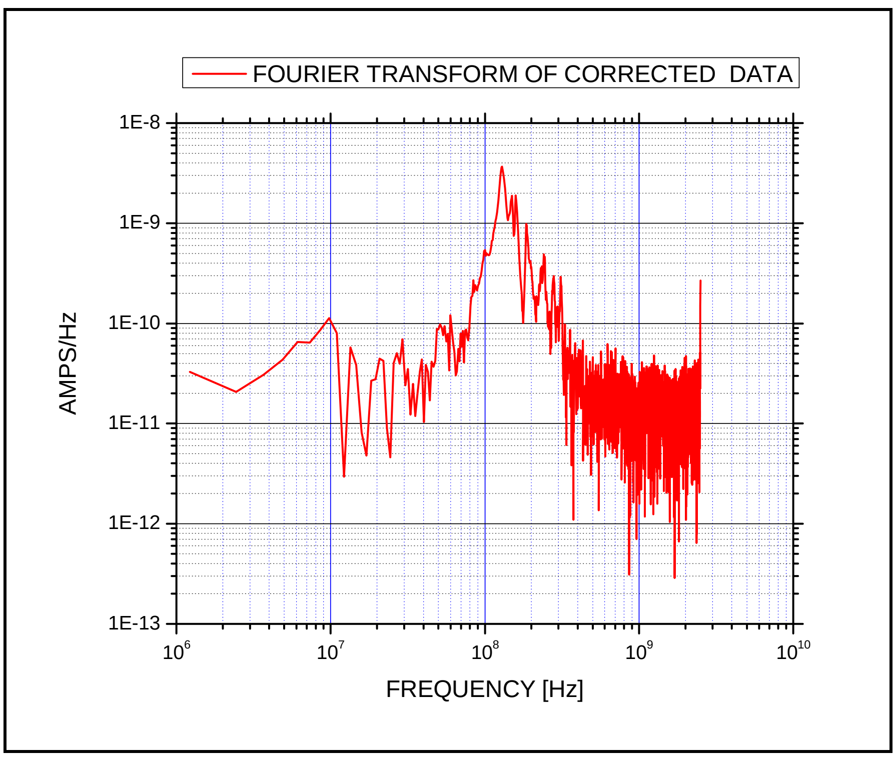

Figure F-7. Induced current Fourier transform.

Figure F-7 illustrates the Fourier transform which is used to calculate the time domain representation of the waveform as follows:

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

a. The resonant frequency (F_o) is the first pole in the frequency domain after the DC level and is displayed on the graph at about 1.3E8.

b. The low (F_l) and high (F_h) frequencies are measured at the 3 dB down points from the peak, with the low frequency being to the left and the high frequency being to the right. If necessary the slope is used to calculate the 3 dB point on signals containing more noise.

c. The bandwidth is the difference between the high and low frequency.

d. The exponential attenuation rate α is calculated by:

$$\alpha = \pi(F_h - F_l)$$

e. Quality factor Q is calculated by:

$$Q = \frac{\beta}{\alpha} = \frac{\pi F_o}{\pi(F_h - F_l)} = \frac{(F_o)}{(F_h - F_l)}$$

f. Damping factor D_f is calculated by:

$$D_f = \frac{1}{2Q}$$

Corrected data also include the rise time and pulse width. The rise time of the signal is the time it takes the signal to increase from 10% of the maximum value to 90% of the maximum value. In a wideband signal this is performed on the voltage, current, or field intensity signal. In some cases, an average of the magnitude of all points greater than 90% of the absolute maximum is used in place of the maximum for determination of the 10% and 90% threshold.

The pulse width of the signal is the time the magnitude of the signal is at the maximum value. This is performed on the voltage, current or field intensity signal. In some cases, an average of the magnitude of all points greater than 90% of the absolute maximum is used in place of the maximum for determination of the 10% and 90% threshold in accordance to the requirements of the test plan.

F.6 DATA RESULTS.

Provided in Table F-1 is a basic overview of the processed data results of the SCALAR quantities for damped sinusoids which were generated from the Fourier transform in Figure F-7.

APPENDIX F. OVERVIEW OF HEMP TEST INSTRUMENTATION AND MATHEMATICS.

TABLE F-1. EXAMPLE OF CALCULATED DAMPED SINUSOID SCALAR VALUES

Test point ID	Orient	Shot#	Peak I (Amp)	Resonant Frequency	Lower Frequency	Higher Frequency	Bandwidth	Alpha	Q
1	2-front	5170	0.1478	1.29E+08	1.26E+08	1.33E+08	8.18E+06	2.38E+07	14.15
2	2-front	5170	0.1030	1.25E+08	1.20E+08	1.30E+08	9.80E+06	3.26E+07	15.67
3	2-front	5170	0.1551	1.63E+08	1.50E+08	1.70E+08	2.00E+07	2.85E+07	15.84

F.7 <u>EXAMPLE TECHNICAL ANALYSIS</u>.

a. From the scalars presented in Table F-1, which were generated from the measured EMP induced current the following is known;

(1) The induced current is at a frequency of 129 MHz,

(2) The bandwidth is approximately 10 MHz,

(3) The Q is large and the damping factor is small indicating the signal is over damped and will decay quickly, and

(4) The amplitude of the induced current was 0.15 amps.

b. Therefore, if the component connected to this cable was experiencing EMP induced problems, it could most likely be eliminated by designing a simple low pass filter (or a more complicated filter based on the circuit signal requirements) with an upper cutoff frequency of 119 MHz and which is capable of carrying the normal signal currents plus approximately 0.2 amperes.

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APPENDIX G. ABBREVIATIONS.

AFEMP	Advanced Fast Electromagnetic Pulse
amp	Ampere
AR	Army Regulation
ATEC	U.S. Army Test and Evaluation Command
BOB	breakout box
CBRN	Chemical, Biological, Radiological, and Nuclear
CDD	Capability Development Document
CI	Current Injection
CONOPS	Concept of Operations
CPD	Capability Production Document
CS	conducted susceptibility
DA	Department of the Army
DAS	data acquisition system
DCSOPS	Deputy Chief of Staff for Operations
Df	damping factor
DM	Design Margin
DOD	Department of Defense
DODD	Department of Defense Directive
DODI	Department of Defense Instruction
DOT&E	Director of Operational Test and Evaluation
DTRA	Defense Threat Reduction Agency
E3	electromagnetic environmental effects
ECP	Engineering Change Proposal
E-Field	electric field
EMP	electromagnetic pulse
FD/SC	Failure Definition/Scoring Criteria
FFT	Fast Fourier Transform
Fo	resonant frequency
GHz	gigahertz
HEMP	High Altitude Electromagnetic Pulse
HF	high frequency
H-Field	magnetic field
HMMWV	high mobility multi-purpose wheeled vehicle
HOB	height-of-burst
HPD	horizontal polarized dipole
Hz	hertz

APPENDIX G. ABBREVIATIONS.

IAP	Independent Assessment Plan
IAW	in accordance with
IEP	Independent Evaluation Plan
kHz	kilohertz
km	kilometer
kV/m	kilovolts per meter
LCNS	Life-Cycle Nuclear Survivability
LF	low frequency
LRU	line replaceable unit
m	meter
m^2	square meter
mA	milliampere
MEF	Mission Essential Functions
MF	middle frequency
MHz	megahertz
MIL-STD	Military Standard
ms	millisecond
NHC	Nuclear Hardening Criteria
NLT	not later than
ns	nanosecond
ODS	optical data system
PAM	pamphlet
PE	Project Engineer
PM	Program Manager
Qf	quality factor
QSTAG	Quadripartite Standardization Agreement
s, sec	second
SCG	security classification guide
SN	serial number
SOP	Standard Operating Procedure
SREMP	Source Region Electromagnetic Pulse
STA	Survivability Test and Assessment
SUT	System Under Test
SVAD	Survivability, Vulnerability, and Assessment Directorate
TO	Test Officer
TOP	Test Operations Procedure

APPENDIX G. ABBREVIATIONS.

µsec	microsecond
UHF	ultra high frequency
USANCA	U.S. Army Nuclear and Combating Weapons of Mass Destruction Agency
VEMP	Vertical Electromagnetic Pulse
VHF	very high frequency
VLF	very low frequency
V/m	volts per meter
WSMR	White Sands Missile Range

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APPENDIX H. GLOSSARY.

Term	Definition
Electromagnetic Pulse	A burst of electromagnetic radiation from a nuclear explosion or a suddenly fluctuating magnetic field. The resulting electric and magnetic fields couple with electrical/electronic systems to produce potentially damaging current and voltage surges.
Source Region Electromagnetic Pulse (SREMP)	A SREMP is produced by low-altitude nuclear burst. An effective net vertical electron current is formed by the asymmetric deposition of electrons in the atmosphere and the ground, and the formation and decay of this current emits a pulse of electromagnetic radiation in directions perpendicular to the current. The asymmetry from a low-altitude explosion occurs because some electrons emitted downward are trapped in the upper millimeter of the Earth's surface while others, moving upward and outward, can travel long distances in the atmosphere, producing ionization and charge separation. A weaker asymmetry can exist for higher altitude explosions due to the density gradient of the atmosphere.
High-altitude Electromagnetic Pulse (HEMP)	HEMP is produced when a nuclear weapon is detonated high above the Earth's surface, creating gamma-radiation that interacts with the atmosphere to create an intense electromagnetic energy field that is harmless to people as it radiates outward but which can overload circuitry with effects similar to, but causing damage much more swiftly than a lightning strike.
Vertical Electromagnetic Pulse	This is the vertical component of a burst of electromagnetic radiation from a nuclear explosion or a suddenly fluctuating magnetic field. The resulting electric and magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges.
Horizontal Electromagnetic Pulse	This is the horizontal component of a burst of electromagnetic radiation from a nuclear explosion or a suddenly fluctuating magnetic field. The resulting electric and magnetic fields may couple with electrical/electronic systems to produce damaging current and voltage surges.

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14. QSTAG 620, Edition 2: Nuclear Survivability Criteria for Communications-Electronics Equipment, 29 January 1993.

For information only (related publications).

a. AR 200-1, Environmental Quality: Environmental Protection and Enhancement, 13 December 2007.

b. AR 200-2, Environmental Effects of Army Actions, 15 January 2006.

c. TOP 01-2-612A Nuclear Environment Survivability, 28 October 2014.

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APPENDIX J. APPROVAL AUTHORITY.

CSTE-TM 9 July 2015

MEMORANDUM FOR

Commanders, All Test Centers
Technical Directors, All Test Centers
Directors, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command

SUBJECT: Test Operations Procedure (TOP) 01-2-620A, High-Altitude Electromagnetic Pulse (HEMP) Testing, Approved for Publication

1. TOP 01-2-620A, High-Altitude Electromagnetic Pulse (HEMP) Testing, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency. The scope of the document is as follows:

This TOP provides methods for the planning and execution of testing Army/Department of Defense (DOD) equipment to determine the effects of a Horizontal Component HEMP environment. The content includes facilities, instrumentation setup, new testing procedures, actual environmental considerations, and data recording and presentation of results. Photos of recommended test equipment and test setups are included, along with some representative data plots. This document incorporates the requirements of Military Standard (MIL-STD)-464C and MIL-STD-2169C, which provide DOD electromagnetic pulse guidance.

2. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

3. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-TM), 2202 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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Date: 2015.07.23 09:19:39 -04'00'

MICHAEL J. ZWIEBEL
Director, Test Management Directorate (G9)

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Forward comments, recommended changes or any pertinent data which may be of use in improving this publication to the following address: Range Infrastructure Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity, Commander, U.S. Army White Sands Missile Range, ATTN: TEDT-WSV, Survivability, Vulnerability and Assessment Directorate, US Army White Sands Missile Range, NM 88002-5002. Additional copies can be requested through the following website: http://itops.dtc.army.mil/RequestForDocuments.aspx, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.