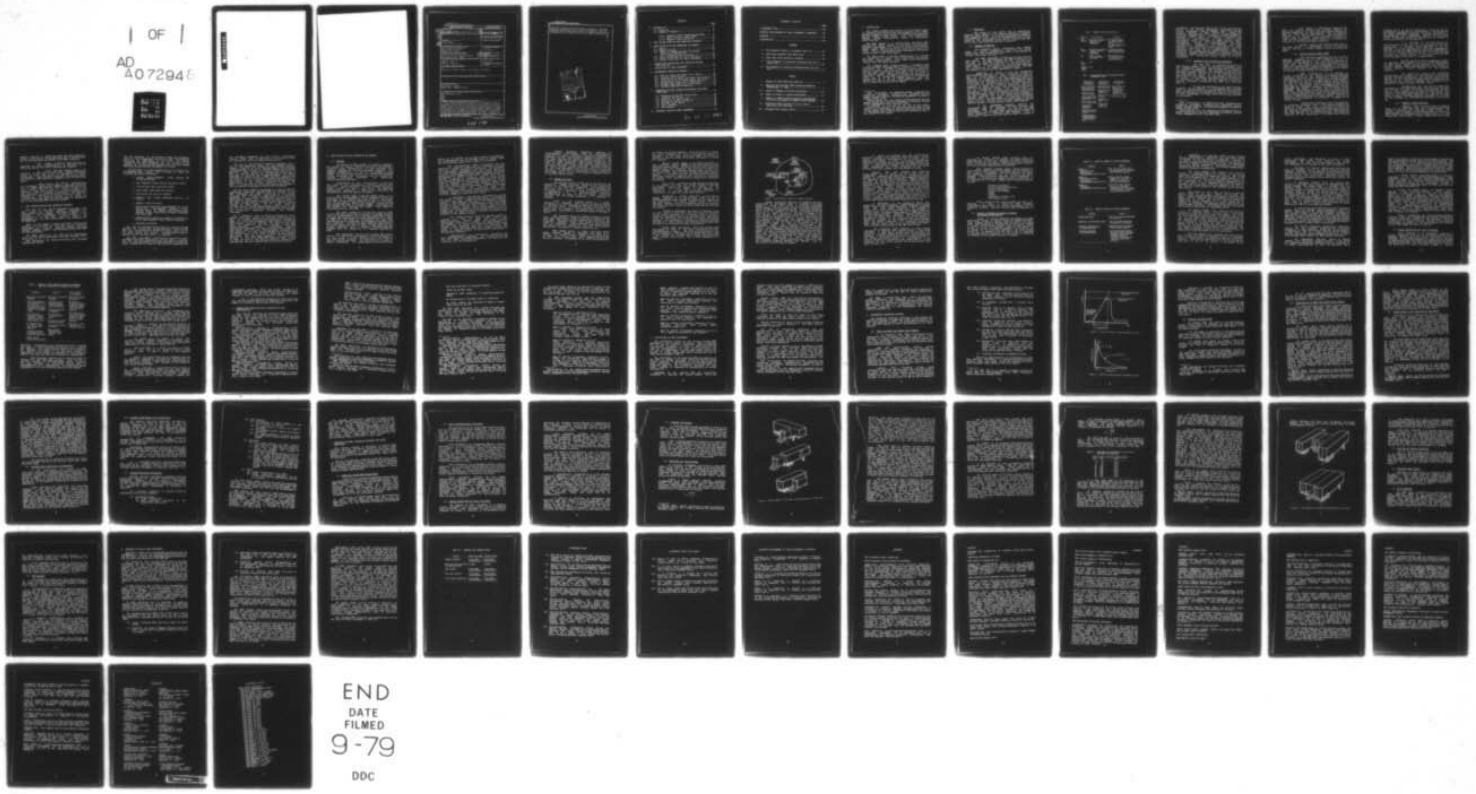
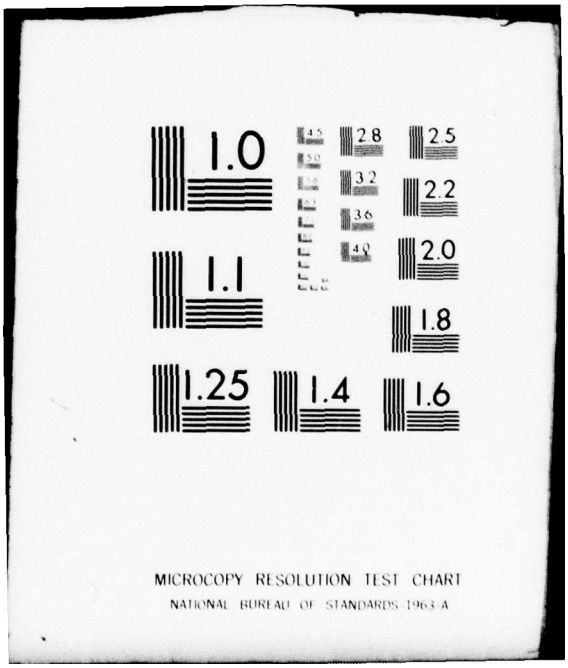
AD-A072 948 HARRY DIAMOND LABS ADELPHI MD F/G 20/14
HEMP STUDY OF PLANNED DAS3 CONFIGURATION.(U)
JUN 79 T A ROSE
UNCLASSIFIED HDL-TR-1891 NL

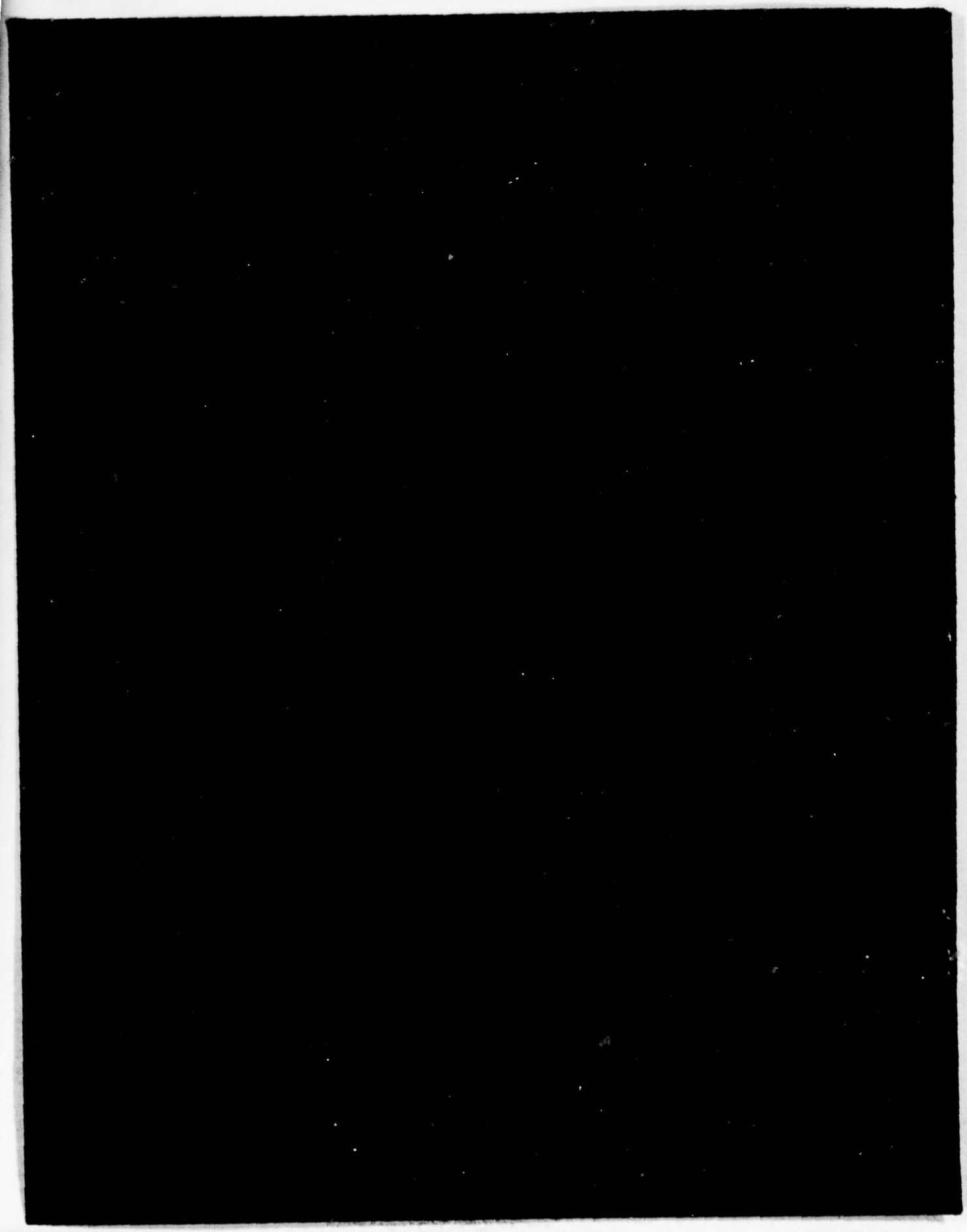
1 OF 1
AD A072948



END
DATE FILMED
9-79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

A072948



UNCLASSIFIED

'ITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: HDL-TR-1891	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): HEMP Study of Planned DAS3 Configuration	5. TYPE OF REPORT & PERIOD COVERED: Technical Report
6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s): Thomas A. Rose	8. CONTRACT OR GRANT NUMBER(s)
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: Prog Elem: O
11. CONTROLLING OFFICE NAME AND ADDRESS: TACMIS Project Manager Office, U.S. Army Computer Systems Command, Fort Belvoir, VA 22060	12. REPORT DATE: June 1979 13. NUMBER OF PAGES: 70
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12) 74 p.	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: E648E1
DRCMS Code: 950000.00.00000

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic pulse
EMP
DAS3
ADPE

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a preliminary study to determine high-altitude electromagnetic pulse (HEMP) protection measures required for the Decentralized Automated Service Support System (DAS3). The DAS3 planned configuration examined consists of automatic data processing equipment (ADPE) housed in an XM971 semitrailer van and powered by commercial power or two MEP-005A, 30 kW, 50/60 Hz, 120/208 V generators. The ADPE is commercial, off-the-shelf computer equipment which is, as yet, not fully

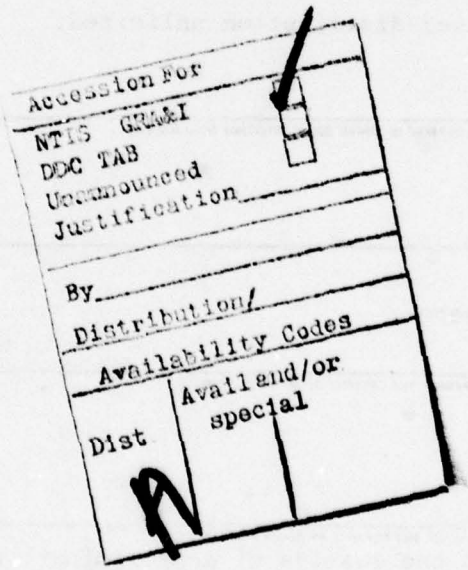
DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

163 050

defined as to manufacturer and specific components. The DAS3 system was examined in order to identify possible or definite weaknesses from an HEMP susceptibility standpoint and to provide recommendations for enhancing the overall HEMP survivability.



CONTENTS

		Page
1.	INTRODUCTION	5
	1.1 Objective	6
	1.2 Summary of Results	6
	1.2.1 Automatic Data Processing Equipment	8
	1.2.2 Mobile Electric Power (MEP)	9
	1.2.3 Magnetic Tapes and Disks	10
2.	DAS3 SYSTEM OVERVIEW AND HARDENING APPROACH	11
3.	HEMP DESCRIPTION AND HARDENING PHILOSOPHY	14
	3.1 General	14
	3.2 Damage and Upset	16
	3.3 Impact of Damage and Upset on System Performance and Mission	20
	3.4 Fault Avoidance/Fault Tolerance	25
	3.5 Design Guidelines for Fault Avoidance	25
	3.6 Design Guidelines for Fault Tolerance	28
4.	ASSUMPTIONS CONCERNING DAS3 CONSTRUCTION AND CONFIGURATION	31
5.	LIMITATIONS OF HEMP ASSESSMENT	35
6.	RECOMMENDED HARDENING MEASURES	37
	6.1 TPD's at Power and Signal Entry Panels	37
	6.2 External System Ground	40
	6.3 Installation of Power and Signal Entry Panels	41
	6.4 Installation of Air Conditioners and Vents	42
	6.5 No Additional Apertures or Penetrators	43
	6.6 Standard Requirement for Closed Doors	44
	6.7 Hardness-Assurance Procedures	44
7.	SUGGESTED OPTIONAL HARDENING MEASURES FOR ADDED CONFIDENCE	46
	7.1 Gasketing around MEP Access Doors	46
	7.2 Internal Van Ground	47
	7.3 Vestibule for Van Entrance	47
	7.4 Ducting for Cables Inside Van	52
	7.5 Shielded Power Cables	52
	7.6 Error Checking	52
	7.7 EMP Detector	53
8.	PROPOSED FOLLOW-UP HEMP ASSESSMENT	54

79 08 17 003

CONTENTS (Cont'd)

Page

LITERATURE CITED 58

SELECTED BIBLIOGRAPHY OF FAULT-TOLERANCE LITERATURE 60

GLOSSARY 61

DISTRIBUTION 69

FIGURES

1. Environmental zones in a complex facility 18

2. Spark gap response time definition 39

3. Spark gap pulse potential waveform 39

4. Three examples of vestibule configurations for a single van 48

5. Two examples of vestibule configurations for two vans 51

TABLES

I. Summary of DAS3 HEMP Survivability 7

II. Required and Optional HEMP Hardening Measures Recommended for DAS3 7

III. Impact of Damage on System Performance 21

IV. Impact of Upset on System Performance 21

V. Summary of HEMP Hardening Measures Recommended for Fault Avoidance for General ADPE Systems 29

VI. Shielding Effectiveness of a 48 by 78-in. Vestibule with Open End 49

VII. Proposed Test Program Effort 57

1. INTRODUCTION

This report presents the results of a preliminary study to determine the high-altitude electromagnetic pulse (HEMP) protection measures required for the Decentralized Automated Service Support System (DAS3). This study examined the planned system configuration based on procurement specifications.[1,2]

The DAS3 system is a decentralized and mobile ADPE configuration whose purpose is to fulfill the functional software requirements of the Direct Support Unit Standard Supply System (DS4) at the retail level of the Army in the field. DS4 is a standardized supply-management information system currently under development.

The DAS3 system, in the DS4 configuration, will provide the capability to handle daily stock control and storage functions, reconciliation, quick supply store procedures, catalog data, and demand analysis.

The proposed DAS3 system consists of automatic data processing (ADP)* equipment (ADPE) installed in a 35-ft-long semitrailer van. The ADPE is powered by either commercial electric power or mobile electric power (MEP) consisting of two MEP-005A 30-kW diesel generators, one of which is provided for backup. The power is 120/208 Vac nominally, at 50/60 Hz. The planned MEP configuration is an AN/MJQ-10A system made up of two PU 406B/M generator sets. The semitrailer van to be used is designated the XM971. This van is a modified version of the XM913.

---

[1]RFP, Solicitation No. DAHC26-78-R-0001, Automated Data Processing Equipment, Decentralized Automated Service Support System; A Mobile, Van-Mounted Management Information System (17 May 1978).

[2]Specification for the Decentralized Automated Service Support System DAS3, Tactical Management Information Systems Project Management Office (February 1978).

*A glossary is included at the end of this report. Included in the glossary are terms and acronyms used in this report which have vague or unknown meaning outside the EMP or ADP communities or which have special meaning as used in the context of this report.

1.1 Objective

The intent of this effort was to examine the proposed DAS3 system to (1) identify possible or probable HEMP susceptibilities, (2) provide corresponding hardening recommendations which could be implemented at the current stage of the procurement cycle, and (3) identify any need for further, more detailed testing or analysis.

1.2 Summary of Results

The following overall conclusions were reached based on certain assumptions concerning the system construction and configuration (see sect. 4) and subject to certain limitations (see sect. 5).

The HEMP assessment of DAS3 was divided into two major parts. One part addressed the HEMP survivability of the ADPE in the XM971 semitrailer van. The other part addressed the HEMP survivability of the mobile electric power (MEP). A third, more minor, question addressed was the vulnerability of magnetic tapes and disks. The HEMP survivability conclusions are summarized in table I.

Summarized in table II are the recommended HEMP-hardening measures for DAS3 (discussed in detail in sect. 6). Those measures listed in the column labelled "Required for protection from both damage and upset" are considered to be required for the predicted damage and upset conclusions for the ADPE to be valid. The measures listed in the other two columns of table II are optional (desired), suggested as means for providing additional margins of protection or added confidence. Any of these measures which can be implemented without cost impact should be implemented. The use of gasketing around MEP access doors and shielded power cables is a measure to assure hardness of the MEP, although this is not known to be necessary or adequate based on this study. The vestibule arrangement could be used if the requirement for closed doors on the van cannot be met. Various of the optional hardening measures could be needed if future analysis reveals deficiencies.

If the recommended hardening measures are implemented and the proposed follow-up analyses are performed, DAS3 is predicted to survive the HEMP environment. The planned DAS3 configuration presents no major roadblocks to achieving HEMP hardness. This is attributed in part to the fact that all ADPE is inclosed in

TABLE I. SUMMARY OF DAS3 HEMP SURVIVABILITY

Category	Survivability	Proposed
ADPE (damage)	Predicted hard assuming required hardening measures are implemented	For added confidence: (1) further analysis once ADPE has been defined (2) verification HEMP simulation test of system
ADPE (upset)	Predicted hard assuming required hardening measures are implemented	For added confidence: further analysis once ADPE has been defined
MEP	Unable to reach a conclusion based on this study	HEMP simulation test to determine coupling to internal and external MEP cables
MEP switch box	Hard	-
Magnetic tapes & disks	Hard	-

TABLE II. REQUIRED AND OPTIONAL HEMP HARDENING MEASURES RECOMMENDED FOR DAS3

Required for damage and upset protection	Desired for damage and upset protection	Desired for upset protection only
Assure that TPD's at power and signal entry panels are adequate for HEMP	Gasketing around MEP access doors	Error checking for memory, all storage devices, and all data transfers both internal and external to system
External system properly grounded	Proper grounding scheme for inside of van	EMP detector scheme
Proper installation of power and signal entry panels	Vestibule for van entrance	
Proper installation of air conditioning	Ducting for cables inside van	
No additional apertures or penetrators	Shielded power cables to protect MEP	
Standard requirement that doors be kept closed		
Hardness-assurance procedures which include maintenance of door gaskets, etc		

a metallic van structure, and in part to the conscientious efforts of the Tactical Management Information Systems Project Management Office (TACMIS PMO). TACMIS PMO carefully selected the XM971 van for its electromagnetic shielding characteristics. Although the ADPE Request for Proposals (RFP)[1,2] does not contain a specific HEMP survivability specification, it does include several requirements which are useful for HEMP protection. These requirements include (1) electromagnetic shielding, (2) power-fail protection, (3) filtering and surge suppression of transients at cable entry panels, (4) power transient protection, and (5) a comprehensive plan for toleration of upset faults (HEMP-transient caused or otherwise) through hardware redundancy, checkpoint rollback procedures, hardware error detection, and standard operating procedures for maintaining backup copies of critical information.

1.2.1 Automatic Data Processing Equipment

The DAS3 ADPE is predicted to be hard to HEMP-induced damage, based on engineering judgement, when the recommended hardening measures described in section 6 are properly implemented. The accuracy of this hardness statement depends especially on the ADPE's compliance with the specifications called for in the DAS3 RFP[1] and the Specifications for DAS3,[2] as highlighted in section 4 of this report. The confidence associated with this prediction is necessarily lower than desired because of a lack of specific equipment information and HEMP test data (see sect. 5).

So that the confidence of the above hardness statement may be improved, it is recommended that a refined study be conducted when the specific ADPE has been defined. Upon availability of a prototype DAS3 system, a limited test is also recommended to further verify the overall hardness of the system.

---

[1]RFP, Solicitation No. DAHC26-78-R-0001, Automated Data Processing Equipment, Decentralized Automated Service Support System; A Mobile, Van-Mounted Management Information System (17 May 1978).

[2]Specification for the Decentralized Automated Service Support System DAS3, Tactical Management Information Systems Project Management Office (February 1978).

With regard to HEMP-induced upset of the ADPE, the required hardware and software measures and planned procedures for upset toleration appear adequate to meet the DAS3 mission requirements. The only possible weakness is in the ability of the system to detect all likely types of upsets. Upset detection is essential in order for the system to be able to carry out its correction, restoration, and recovery/restart measures.

Further study of the specific ADPE, when it has been defined, is recommended in order to verify the system's ability to detect upsets likely to be caused by HEMP.

1.2.2 Mobile Electric Power (MEP)

This analytical assessment did not provide a definite statement on the HEMP susceptibility of the MEP-005A, 30-kW generator set. No specific component or circuit was identified as definitely vulnerable. On the other hand, the presence of a large number of inherently sensitive semiconductor components embedded in the complex control circuits of the generator provides sufficient reason to question the HEMP hardness of the generator.

HEMP vulnerability of the MEP-005A is further indicated by the results of an unpublished HEMP assessment and brief test conducted by the Harry Diamond Laboratories (HDL) in 1975. In that study a 15-kW generator was addressed as part of an examination of possible MEP to be used by the Patriot (formerly SAM-D) missile system. According to discussions with knowledgeable staff at the Army Mobility Equipment Research and Development Command (MERADCOM) MEP group, the 15-kW unit is similar to the MEP-005A. Unfortunately, sufficient details concerning the HEMP study of the 15-kW unit could not be obtained and as a result extrapolation of the results to the MEP-005A was not possible. What information was found, however, leads one to believe the 15-kW generator is vulnerable. A summary of the results follows.

Testing was conducted on the 15-kW generator to determine hardening fixes. This testing examined two types of fixes. The first fix consisted of sanding the periphery of the generator access doors where they mate with the generator inclosure; a conductive silver-based chemical was then applied to the mating surfaces. The second fix consisted of the installation of an additional honeycomb

aluminum grill to the air intake port. The first fix was implemented and seemed to prove sufficient. The second fix was never permanently installed. No formal conclusions or recommendations were documented. Because of the limited nature of the test, no official HDL position was reached as to the survivability of the generator.

It is important to note that neither the above-mentioned fixes nor any similar measures have been incorporated on standard 15-kW generators or on the MEP-005A. It is also interesting to note that the generator used for the Patriot HEMP study was examined at MERADCOM and the first fix was evident on the unit. The silver-painted surfaces had rusted severely to the point where any HEMP shielding benefit from the fix is questionable.

The only way to be able to adequately assess the MEP-005A HEMP susceptibility is to obtain measurements of HEMP energy coupled to the generator via internal and external cabling. These coupling data would then be used to conduct detailed circuit analysis on the MEP-005A circuitry.

The switch box used in the AN/MJQ-10A configuration to connect the two MEP-005A units should survive the HEMP environment. Initially the switch box was thought to be a possible problem; however, examination of the switch box circuitry revealed the presence of only mechanical switches and neon indicator lights.

Consideration was also given to physically disconnecting the backup generator from the switch box when not in use in order to isolate the generator and thus protect it from HEMP transients induced on the cables. This step is not considered necessary in light of the short length of cables interconnecting the generators and in light of the presence of the mechanical switches in the switch box.

1.2.3 Magnetic Tapes and Disks

Magnetic tapes and disks when in a passive state can be considered hard to all expected HEMP field levels, including all postulated threat levels. Any possible upset or damage to such storage media is limited to that caused by the equipment which accesses them (i.e., tape drives and disk drives). Further, tapes and disks are not

normally subject to damage and upset even when mounted on drives unless read or write operations are in progress when the drives experience the effects of an HEMP transient.

The hardness of passive tapes and disks is supported by other investigations, as indicated by the following excerpt from a Bell Laboratories document:[3]

". . . tests show that magnetic tape is not sensitive to EMP even at high levels. Repeated exposures failed to cause data errors or degradation of stored information. Such alteration requires a few hundred gauss, while typically EMP generates a magnetic field of only a few gauss."

These results are further supported by a test conducted by HDL, where magnetic tapes were subjected to the AESOP HEMP simulator which produced 55 kV/m at the tape location (28.3 m out, 30 m radial distance from antenna). Tapes were located on a 1.4-m-high wooden pallet and configured in numerous orientations. The tapes were subjected to 6 pulses at 10-minute intervals for each of 6 orientations. The complete contents of all tapes was verified before and after testing and showed no degradation due to the simulated HEMP field environment.

2. DAS3 SYSTEM OVERVIEW AND HARDENING APPROACH

DAS3 and the new DS4 are scheduled to be used in the near future to provide logistics management for nondivisional Direct Support Unit/General Support Units (DSU/GSU). The development of DS4 software is the responsibility of the Army Logistics Center. The development of the total DAS3 system is the responsibility of TACMIS PMO.

DAS3 is to be modular in design to permit tailoring and expansion of the ADPE so that DAS3 can be a potential replacement for divisional, separate brigade, and corps support, command, supply, and maintenance functional ADPE for 1981 and beyond.

The XM971 semitrailer van, MEP, and air-conditioning units for the van are government-furnished equipment (GFE).

---

[3]EMP Engineering and Design Principles, Bell Telephone Laboratories (1975).

The ADP equipment is off-the-shelf commercial equipment, which is not ruggedized for military use. The proposals concerning the procurement of the initial 193 systems (including the ADPE hardware) and the installation and assembly of the GFE and ADP hardware into the final system have been being evaluated throughout this study.

The DAS3 ADPE in its DS4 configuration will consist of a minicomputer-type system which includes at least the following peripheral equipment.

1 system console-keyboard visual display and printing terminal

2 user keyboard visual display terminals (KVDT)

1 line printer (200 lines per minute)

1 card reader (200 cards per minute)

1 card punch (35 cards per minute)

2 magnetic tape drives (800/1600 bits/in., 35 in./s)

1 magnetic tape controller

3 disk drives controlled interchangeably by 2 disk controllers (120-megabyte capacity total, 180,000 bytes per second data transfer rate, average access time 60 ms or faster, removable disk pack type)

1 communications controller capable of controlling up to eight keyboard visual display terminals

1 keypunch/interpreter

Any two of the three disk drives will provide storage capacity for 100-percent system operation. Either of the two disk controllers will be able to control any or all of the three system disk drives. A backup system console, possibly one of the user KVDT's, is required.

The DAS3 procurement specifications provide for fault avoidance and fault tolerance at various levels. A partial list of such requirements includes transient filtering and surge suppression for exterior cabling which penetrates the

van, hardware redundancy for disk drives, a checkpoint rollback (CPRB) mode of operation for all software, power fail protection, and error detection/correction.

The use of off-the-shelf commercial equipment that is not military-ruggedized makes the DAS3 somewhat unusual. Indeed, virtually all past HEMP assessments have addressed custom-designed military or Defense Communications System equipment. DAS3 represents a growing trend, especially in ADP, to minimize design and engineering costs by taking advantage of existing and proven equipment. The logical extension of this philosophy to HEMP hardening suggests that one should strive to achieve hardness through design or modification of the system inclosure rather than through modification of the existing electronic equipment. For DAS3, it is desirable to limit modifications and changes to the van shelter or equipment installation procedures.

For the latter reason, and because of a lack of specific information concerning the DAS3 ADPE, the emphasis of this HEMP assessment was toward protection at the overall shielding level (van walls). Such protection is considered achievable for a system like DAS3 which is concerned with HEMP-induced damage only. (Protection against upset by shielding of the system inclosure is much more difficult.) The DAS3 system mission is such that it need not operate through an HEMP event. As a result, DAS3 can cost-effectively protect against HEMP-induced upset through its use of various fault-tolerance measures such as power fail protection, checkpoint rollback, and hardware redundancy.

As a tangential note, it should be pointed out that a general Army need exists for shelters, specifically the 35-ft van variety, that have been specifically hardened to HEMP. It is felt that substantial improvements in shielding effectiveness could be achieved over presently available vans, at relatively low cost, through a good HEMP shelter-hardening program. Furthermore, specific quantitative knowledge of HEMP shielding effectiveness of vans would help to avoid low-confidence hardening and overhardening. An Army product manager who is fielding a new system needs to be able to select an HEMP-hardened semitrailer van from Army inventory. The alternative approach is that which TACMIS PMO faced with DAS3: trying to make do with a van which is carefully selected but, nevertheless, may have unknown HEMP shielding attributes.

3. HEMP DESCRIPTION AND HARDENING PHILOSOPHY

3.1 General

The effects of HEMP on ADPE, or computer equipment, are worthy of special attention because of the inherent, relatively high, susceptibility of such equipment as a category compared to military equipment in general. This inherent susceptibility is due to the presence of large numbers of electronic circuits in all present-day computer central processors and controllers and in virtually all computer peripheral equipment and stand-alone record-processing equipment.

Contributing to this susceptibility is the fact that much of this electronics is low-level digital logic circuitry. These electronic circuits normally operate at signal levels of only a few volts. The countless semiconductor components in these circuits inherently can dissipate only very low amounts of energy.

The acronym HEMP (sometimes HAEMP) refers to the high-altitude electromagnetic pulse phenomenon which is a by-product of a high-altitude nuclear burst. The broader term EMP includes various categories of EMP, all associated with nuclear bursts. HEMP is one category. Others are the low-altitude EMP (LEMP or sometimes LAEMP), system-generated EMP (SGEMP), and internal EMP (IEMP). This report is concerned primarily with HEMP.

The major reason for limiting this report to HEMP is the high field levels and large area of coverage expected from an exoatmospheric burst. Nuclear explosions at lower altitudes can be expected to produce comparable field levels to HEMP but the areas of illumination are much more constrained and the waveshapes and propagation character are very different. Further, at lower altitudes other effects of nuclear explosions, such as blast, thermal radiation, and nuclear radiation, tend to dominate. Hardening measures proposed here are compatible with measures required for LEMP.

The postulated tactical and strategic EMP threats consist of a high-level electromagnetic field environment in the area around a system. The amplitude of this field is tens of kilovolts per meter. The field rises to its peak in several nanoseconds. For exoatmospheric bursts the field

decays to 10 percent of its peak in about a microsecond. For endoatmospheric bursts the peak level is slightly lower and the 10-percent decay time is about a millisecond.

The high-amplitude HEMP environment has the potential of producing large electrical transients on system electrical cables and metallic structures. The transients are subsequently propagated into the system electronic circuits. Unless HEMP protection measures exist, the system can be seriously damaged or disrupted. Component burnout or degradation is highly likely in circuits that (1) are directly connected to telephone, power, or signal cables that extend unprotected into the HEMP environment or (2) are directly connected to input/output signal or power cables that run between peripherals and equipment racks in a marginally shielded system environment. Components embedded more deeply within the circuits, away from transient-carrying media, are typically less likely to fail, although, because of inherent nonlinearities in electronic circuits, damage and upset can still occur.

A particular, very serious, vulnerability problem for digital circuits in computer equipment is the potential disruption of logic states and the alteration of digital signals. HEMP-produced transients can distribute energy throughout the system via interconnecting power and signal wiring, affecting circuit input levels, power bias, and reference levels. Further, the resultant change in circuit outputs and performance can cause disruptive effects to be transmitted to other circuits, ultimately disrupting large portions of the computer system.

The present trend of designing computer systems to function at lower and lower logic levels and power-dissipation levels makes the upset problem increasingly difficult to prevent. For many systems it is not realistic to shield or otherwise protect the system elements from transients that will be disruptive. The result is that measures often must be taken to permit the system to tolerate upsets, so that overall performance is not adversely affected.

Semiconductors are traditionally considered the most HEMP-sensitive components. But it should be pointed out that other electrical components, like capacitors and resistors, are also susceptible.

Common hardening protection measures for electromagnetic interference (EMI) and electromagnetic compatibility (EMC), lightning, electrical overloads, and brownouts provide some protection against the HEMP threat, but these measures fall short of adequate protection. The frequency range of the HEMP threat is much broader than for some of these phenomena. HEMP-induced transients are typically much higher in amplitude than transients caused by the other effects (except lightning). Protection devices for the other phenomena, that shield, divert, or dissipate transients, either fail to react quickly enough, operate at the wrong levels, or fail to eliminate an adequate portion of the HEMP-induced energy.

3.2 Damage and Upset

The problems caused by HEMP can be divided into two categories: damage and upset. Damage is the irreversible failure of an electrical component. This typically can occur at levels as low as 50 V. Examples of damage are (1) burnout of a transistor, diode, or integrated circuit, (2) degradation of a semiconductor's operating characteristics so that it will no longer function as intended, and (3) voltage breakdown of a capacitor or resistor.

Upset is the unwanted action of a system, subsystem, or component. Upset typically occurs at levels on the order of 1 V. Examples of upset are (1) altering of a flip-flop state, (2) altering of one or more bits in a memory word or register, (3) communication errors, and (4) misread, miswritten, or overwritten areas of storage or memory.

The threshold levels for damage and upset provided above are approximate. Actual levels are a function of not only peak level but also the frequency and duration of the transient. Threshold levels vary greatly for different types of components. Wide variations in threshold levels can exist even for devices of the same kind from one manufacturer, produced on a common production run.

When damage occurs it almost invariably causes upset. However, damage is separated from upset as a category for several reasons. Damage is, from many points of view, more serious than upset. Damage requires that service personnel be summoned to run tests and diagnostics

to isolate the failed component. Once the failure is found, the faulty component or circuit card must be repaired or replaced. On the other hand, with upset, the system can continue to function after the altered information or states are restored.

Another reason damage is considered separately is that hardening against damage is much less expensive than hardening against upset. The shielding and other protective measures used for hardening are difficult to apply to a degree adequate for protection against upset, which occurs at levels more than an order of magnitude lower than for damage. If a system's mission does not require continuous real-time operation, then the upset problem can frequently be handled more cost-effectively through fault-toleration procedures.

The primary objective of HEMP hardening generally is to attempt to block the energy present in the HEMP environment outside the system from getting into the electronics. If this effort is not adequate, the alternative is to make the electronics resistant to transients or to make the system fault tolerant.

Protecting a typical electronic circuit against damage requires, as a rule-of-thumb, about 60 dB of shielding effectiveness between the external environment and the electronics. To protect against upset, 100 dB is required. Greater levels of protection are usually required for cables and other conductors which penetrate the shielded environment.

Systems or subsystems are normally contained in one or more levels of shielding. The first level of shielding (first shield boundary) is the overall inclosure, either a building, electronics shelter, or equipment box. Additional levels of shielding are provided if within the overall structure the equipment is installed in effective shielded cabinets or boxes. Normal rack mounting of equipment does not qualify as an effective means of shielding.

Common HEMP terminology labels the external HEMP environment as zone 0. The area inclosed by the first shield boundary is zone 1. The first shield boundary is the zone 0/1 boundary. Additional shield boundaries within zone 1 may inclose one or more zone 2 levels, and within them zone 3 levels, and so forth. This is shown conceptually in figure 1.

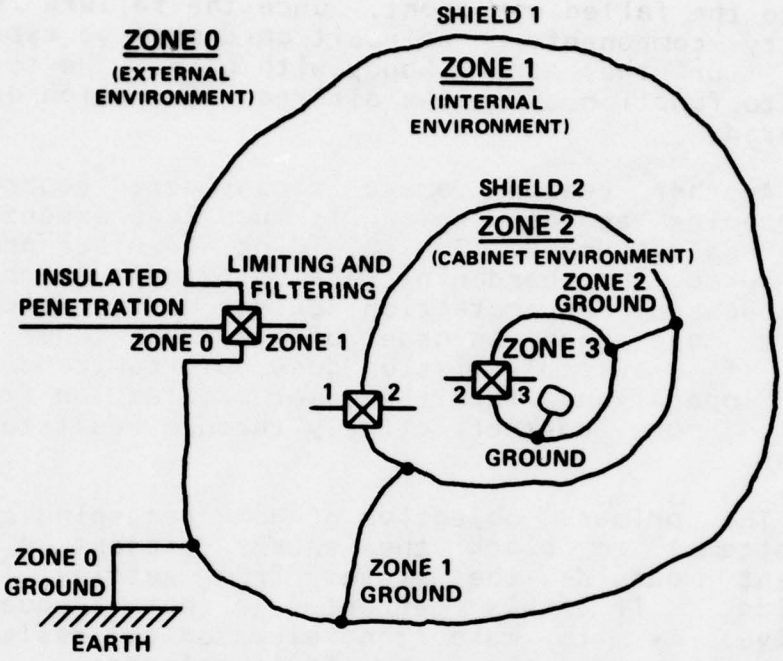


Figure 1. Environmental zones in a complex facility.

Common electronics shelters, for example, that are constructed of corrugated steel or aluminum with seams welded or riveted, can provide up to 60 dB of shielding effectiveness. If this figure is met, no further protection would be needed for damage hardening. Additional hardening would still be needed, of course, to provide the 100 dB required for upset protection. But even if damage is the only concern, an electronics shelter will not provide the needed 60 dB of protection unless it is well constructed and all potential factors that can degrade the shielding effectiveness of the shelter are properly handled. Any of many possible types of flaws in the overall shield can drastically reduce the shielding effectiveness. One unshielded cable, without terminal protection devices (TPD's), that penetrates a shield boundary, can effectively negate all the shielding effectiveness otherwise provided. Actual military electronics shelters have been seen to have less than 20 dB of shielding effectiveness. One important factor to consider is that even if a system environment is designed and constructed to have a high shielding effectiveness, after normal operation over a period of time the shielding measures employed may degrade. This is particularly true for mobile systems.

It should be stressed that the rule-of-thumb shielding figures given above are gross estimates. Actual overall attenuation requirements for a system may be substantially higher or lower. For example, a moderately long run of unshielded cable, entering a system shelter, can couple a great amount of energy into the system, requiring surge suppression and filter protection at the cable entrance point much greater than the 60/100-dB values.

Factors that can degrade the shielding effectiveness of a shield can be divided into two categories: apertures and penetrators. An aperture is any opening in the shield that allows electromagnetic radiation to penetrate the shielded environment. Common examples of apertures are windows, doors, and vents. Special shielding measures must be applied to all apertures to avoid serious degradation of the potential shielding effectiveness of the shield boundary. Often windows can be eliminated altogether. Vents should be covered with good electrically conductive grates that are well bonded electrically to the overall shield boundary. Doors should be fitted with electrically conductive gasketing around the edges so as to provide a good continuous perimeter seal when the door is closed. Standard operating procedures should call for doors to be closed except for personnel entering and exiting.

A penetrator is any conductive medium that penetrates the shield boundary. Common penetrators include pipes, power lines, ground conductors, antennas, telephone lines, and other signal conductors. Any antenna or unshielded run of pipe or cable acts like a highly effective antenna which can couple large amounts of HEMP energy into the shielded environment. Therefore, external cables should be well shielded where possible. The shields should be peripherally bonded to the connectors and the connectors should be grounded to the outside of the shield boundary which the cables penetrate. All conductors should have TPD's applied where they enter the shielded environment. TPD's include surge-suppression devices and filters.

The grounding system employed is also of great importance in assuring the maximum benefit from system shielding. A good earth ground must be provided. All exteriors of shield boundaries should be interconnected and connected to earth ground with as short a path as possible. The system electronics should be interconnected in an orderly pattern to a floating system ground that is in turn connected to the shield ground and to earth ground (see sect. 6.2 and 7.2).

To harden against upset, multiple levels of shielding are required to provide an overall shielding effectiveness of 100 dB. Instead of 100 dB of shielding, which is difficult to obtain, transient-resistant circuitry and fault-tolerant measures may be employed.

Most computer systems employ fault tolerance to some extent to assure that the equipment performs adequately under normal environments. The normal measures are useful for HEMP-upset protection but are typically not nearly adequate. Fault-tolerance measures can be implemented in hardware or software, as standard operating procedures, or as combinations of these. Common fault-tolerance measures include

hardware redundancy,
error detection/correction,
process redundancy,
plausibility checks,
traps,
timers,
checkpoint rollback, and
instruction retry.

Once a system is built hard to HEMP, the job is not complete. To insure a continuing HEMP hardness, requirements must exist for proper maintenance for all hardening measures. Periodic testing might be necessary as well.

3.3 Impact of Damage and Upset on System Performance and Mission

Tables III and IV summarize the effects on system performance caused by logical classes of damage and upset. These classes reflect problems that can occur if less than total HEMP hardening is incorporated in the system. Damage is broken up into three classes. Each involves failure of either a circuit or a complete subsystem or peripheral due to damage of an individual component. The three classes differ in (1) whether or not the lost circuit or subsystem is redundant and (2) whether or not the circuit or subsystem is critical to the system function of interest.

TABLE III. IMPACT OF DAMAGE ON SYSTEM PERFORMANCE

Problem	Impact
Damage in system-critical, nonredundant subsystem/peripheral/circuit	Total loss of system until failed element is isolated and repaired/replaced
Damage in nonsystem-critical, nonredundant subsystem/peripheral/circuit	Partial loss of system capability until failed element is isolated and repaired/replaced
Damage in redundant subsystem/peripheral/circuit	Partial or total loss of ability to withstand subsequent failures until failed element is isolated and repaired/replaced

TABLE IV. IMPACT OF UPSET ON SYSTEM PERFORMANCE

Problem	Impact
Undetected upset	Incorrect system performance; no solution
Detected, uncorrectable upset	Loss of system/subsystem/ peripheral; no solution
Detected, automatically correctable upset	Degraded system throughput, slow system response
Detected, manually correctable upset	Loss of system/subsystem/ peripheral until operator restores information or hardware states to pre-upset condition and restarts interrupted activity

Redundancy, as used here, refers to the existence of a (functionally equivalent and available) backup replacement for the lost circuit or subsystem. A backup, if it exists, may be automatically switched in or may require operator intervention to be brought on-line. The backup may be a hot backup (powered-up and operating), warm backup (powered-up but not in use), or cold backup (powered-down, possibly physically disconnected).

The first damage class concerns the loss of a circuit or subsystem which is critical to the system operation and for which no backup unit exists. This is the most serious damage class. The most common example is loss of all or part of the central processor unit, memory, or main interface bus. In most systems no redundancy exists for such units. Other examples might exist for specific systems such as the loss of the only magnetic tape drive or the loss of a disk controller that controls one or more key disk drives.

The result of this type of failure is that the entire system is lost until repairs can be made. The repairs might consume anywhere from several minutes to many days. Service personnel must be summoned to run tests and diagnostics to isolate the failure. Once the failure is found, the faulty components or circuit boards must be repaired or replaced. The necessary spare parts may or may not be readily available. Considerable time may be consumed obtaining and installing the replacement parts.

The second damage class refers to the loss of a circuit or subsystem which is not critical to the system operation and does not have an available backup. This class is not as serious as the previous. An example might be the loss of the system tape drives where those tape drives are not required for normal operation. They may only be used for installation of new software and/or for generation of backup copies of software and data. The result of the failure is that only certain system capabilities are lost. The system's primary mission can still be performed. The same repair procedure as outlined for the previous class is required to bring the system up to full operation.

The third damage class is perhaps the least serious and involves the loss of a redundant circuit or subsystem. Since a backup exists, the system can continue to function normally. The result of the failure is that the system has lost part or all of its ability to withstand future

(i.e., penetrators and apertures) in order to block substantial HEMP energy from entering the system environment. All that can be done should be done to take full advantage of the presence of any shield boundaries.

Shielding of external cables which penetrate the zone 0/1 boundary can be an effective means of reducing unwanted transients. This technique is more expensive than installation of TPD's for long cables and often the designer has no control over this area. Commercial power and telephone service are examples where cable modifications are usually impossible.

A desirable measure which can provide good isolation from power-line transients is implementation of a design whereby the system power is isolated from the external power. This could involve using battery power as the direct source of system power while using the externally supplied power to charge the battery system. Effective isolation between the two parts of the power-supply system is obtainable and is commonly provided in commercially available uninterruptable power supply system designs. The cost of such a system is commonly considered too great for many uses, but the benefits for HEMP protection are quite good. Such a system is highly desirable even for normal operation of ADPE in a non-HEMP environment.

It can also be quite effective to shield intrasite cables, which run between system components. Here it is usually cost-effective to employ shielding, as cable runs are typically short between ADP elements. Shielding is competitive with terminal protection for intrasite cabling. The cost benefits of protecting intrasite cabling increase dramatically if similar protection is provided consistently to all such cables, and especially if this cabling connects equipment within a further level of shielding.

The rapidly developing technology of fiber-optic cabling can be extremely effective for eliminating propagation of HEMP transients between ADP system elements. A fiber-optic link is a good solution for an intrasite cabling application where problems are expected, as such a link provides total immunity to HEMP-induced transients.

All unnecessary apertures should be removed (sealed) from the overall system inclosure. If the system 0/1 boundary provides any reasonable level of shielding, it is highly cost-effective to treat all apertures. Doors

should be properly fitted with radio frequency interference (RFI) gasketing and should remain closed when possible. The degrading effects of an open door are so significant that for systems where a door must be opened often, the designer should consider installation of a double-door/vestibule type of arrangement. Vents and other apertures which must remain open can be fitted with honeycomb grills or similar shields which will help to minimize penetration of HEMP energy.

A proper overall grounding scheme is a necessary complement to the other fault-avoidance measures. A good grounding system will serve to assure maximum benefit from system shielding by providing an easy and direct path by which transient energy can be dissipated. Further, a single-point-system grounding scheme is highly desirable for enhancing HEMP survivability.

During the design phase, the designer should consider using transient-resistant circuit designs. Wherever no additional cost is incurred, such measures should by all means be employed. Applying such measures where there is limited increased cost is further recommended for situations involving (1) circuits which are critical to the system mission, (2) components and circuits which are electrically near HEMP ports of entry, and (3) components which are particularly sensitive to HEMP-induced transients. Selective implementation of transient-resistant circuit designs is more cost-effective than later application of fault-tolerance measures except where large cost increases are involved.

Table V summarizes the fault-avoidance measures discussed above and recommended for general systems which include significant amounts of ADP equipment. They are categorized as either required, desired, or providing an extra margin of protection. All these measures are relevant to both HEMP damage and upset protection.

3.6 Design Guidelines for Fault Tolerance

Fault tolerance is an arrangement permitting a system, subsystem, or circuit to continue to operate in the expected manner in spite of a fault. Electrical circuitry, software, or operating procedures are specifically designed or supplemented such that faults are detected and are either ignored or corrected. The term "expected manner" is used in the definition of fault tolerance instead of "correct

TABLE V. SUMMARY OF HEMP HARDENING MEASURES RECOMMENDED FOR FAULT AVOIDANCE FOR GENERAL ADPE SYSTEMS

Required	Desired	Extra margin of protection
Good zone 0/1 shield boundary	Good zone 1/2 shield boundary	Additional shield boundaries
Surge suppression & filtering applied to all zone 0/1 boundary penetrators including all power, signal, & telephone lines	Shielding of all external cables which penetrate zone 0/1 boundary	Shielding of intrasite cables, especially where system has good zone 1/2 shield boundary
All unnecessary apertures avoided (sealed); proper installations of all entry panels, etc	Two-door/vestibule arrangement	TPD's applied to intrasite cabling especially where system has good zone 1/2 shield boundary
RFI gasketing on all doors; doors shut as much as possible	Grills/shields installed on all vents	Fiber-optic links employed for intrasite cabling
Two-door/vestibule arrangement where doors are open often	Single-point-system grounding scheme	
Proper overall system ground scheme	Transient-resistant circuitry	
	Power system isolated from external power supply	

behavior." Correctness of an information process is beyond the scope of fault tolerance as used here, as it involves the adequacy of the specifications made by the originator. For example, the design of an unsuitable process or algorithm by the originator or programmer can yield expected behavior that does not meet the originator's intended goal.

Fault-tolerance measures are an effective means of dealing with the HEMP-upset problem. They are not a realistic approach to the HEMP-damage problem. Typically the best approach to protecting against upset is implementation of a comprehensive fault-avoidance scheme supplemented with fault-tolerance measures where needed.

Any system which includes significant amounts of ADP equipment and does not include all those fault-avoidance measures listed as required and desired in section 3.5 must employ fault tolerance in order to protect against HEMP-induced upset. All computer systems include some fault tolerance to enable the system to operate through normal problems. Usually much more is required than those normal fault-tolerance measures used to prevent upsets caused by non-HEMP causes. Fault tolerance cannot be the sole protection scheme. Fault tolerance must supplement a good implementation of fault-avoidance measures.

For HEMP-upset protection, the recommended fault tolerance should include, as a minimum, error-checking schemes for all stored information (including memory and all storage devices) and all data transfers, both internal and external to the system. Duplicate copies of all critical information must be maintained on HEMP-hard storage media.

A fault is defined as any abnormal condition of hardware, software, or data that may cause a deviation of the information-processing behavior from the expected and desired sequence. A fault may be due to a component failure (damage) or may be associated with any of the various types of upset conditions. The term fault as used here refers to physical faults only. Man-made faults are not included.

All system parts are subject to faults. This includes hardware elements, programs, microprograms, data, input and output signals, inter-system and intra-system communications, and man-machine communications.

The occurrence of a fault can result in either partial or total loss of the system or function unless provisions exist to cause a return to the expected behavior.

Faults are caused either by (1) permanent failures of hardware components, (2) temporary malfunctions of components, (3) external interference with system operation, and (4) human mistakes. This document is only concerned with faults caused by HEMP.

Fault tolerance is a specialized field of study in the information-processing arena and has been growing quickly in recent years because of the movement of computer processing into numerous new applications, especially critical applications involving strategic defense and

life-support missions. While the normal reliability of components used in ADPE has improved by orders of magnitude, this use of ADPE in critical applications has caused interest in fault tolerance to grow and surface.

For a more detailed discussion of fault-tolerance and fault-tolerance measures for HEMP-upset protection, the reader is directed to the selected bibliography.

4. ASSUMPTIONS CONCERNING DAS3 CONSTRUCTION AND CONFIGURATION

This section describes the assumptions made concerning the DAS3 system for purposes of this HEMP assessment. Primarily, the assumptions are concerned with the physical makeup of the system and how it is to be configured for operation. Besides the specifications and the published works[4-9] referred to, the following unpublished documentation was also used:

---

[4]TM9-2330-271-14, Operator's, Organizational, Direct Support and General Support Maintenance Manual, Semitrailer, Van: Electronic 10-Ton, 4 Wheel, Including XM913 (12 May 1972), Including updates through Change No. 2 (26 Nov 1976).

[5]TM5-6115-365-15, Organizational, DS, GS and Depot Maintenance Manual Including Repair Parts and Special Tools List, Generator Sets, Gasoline and Diesel Engine Driven, Trailer Mounted, Including PU 406/M (May 1966).

[6]TM5-6115-465-12, Operator and Organizational Maintenance Manual, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, Including MEP-005A (January 1975), Including updates through Change No. 2 (14 February 1977).

[7]TM5-6115-465-24P, Technical Manual, Organizational, Intermediate (Field) (Direct Support and General Support) and Depot Maintenance Repair Parts and Special Tools List, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, Including MEP-005A (February 1977).

[8]TM5-6115-465-34, Intermediate (Field) (Direct and General Support) and Depot Level Maintenance Manual, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, Including MEP-005A (January 1975).

[9]Report of Test on Radio Frequency Attenuation of Trailer XM703, Miller Trailers, Inc., Electronic Communications, Inc., 4-1160 (6 July 1965).

XM971 Semitrailer Van engineering drawing package; part included in DAS3 RFP and part supplied by Otto Plier, Army Tank Automotive Materiel Readiness Command (TARCOM).

TM5-6115-365-15, draft, supplied 17 July 1978 by William Divins, Army Troop Support and Aviation Materiel Readiness Command (TSARCOM); chapter 25: Generator Set, PU 406B/M; chapter 28: Power Plant, Electric, Trailer Mounted, AN/MJQ-10A.

The XM703 RFI test report[9] relates to equipment which is similar but not identical to equipment associated with the DAS3 system. Numerous other documents, including military standards and specifications, were examined but are not included as references.

The physical nature of the DAS3 system is based on the above-cited documents as well as conversations with representatives of the responsible Army agencies, including TARCOM, TSARCOM, MERADCOM, Tobyhanna Army Depot, and TACMIS PMO. In addition, on-site inspections were made of several standard MEP-005A generator sets and prototype XM971 semitrailer vans.

Knowledge of the DAS3 ADPE is limited to the functional description and performance specifications.[2] It is assumed that up to eight computer terminals (KVDT's) might be outside the DAS3 van and connected by an unknown type of cabling through the van signal-entry panel to the central system ADPE. It is further assumed that WD-1 field wire of undetermined lengths will run to the van signal-entry panel to provide service to a field phone inside the van.

The XM971 semitrailer van (defined by the engineering drawing package) to be used is a modified form of the common XM913 van.[3] The XM971, provided for DAS3, differs from the XM913 in the following ways.

---

[2]Specification for the Decentralized Automated Service Support System DAS3, Tactical Management Information Systems Project Management Office (February 1978).

[3]EMP Engineering and Design Principles, Bell Telephone Laboratories (1975).

[9]Report of Test on Radio Frequency Attenuation of Trailer XM703, Miller Trailers, Inc., Electronic Communications, Inc., 4-1160 (6 July 1965).

The curb side door is relocated forward.

There are no door vents.

Conductive mesh gasketing is installed around all doors.

No inside walls or finished floor is installed.

No entry panels are installed for power or signal cable entry to the van.

The DAS3 ADPE contractor will install the power and signal-entry panels and air-conditioning units, and finish the interior of the van. An unusual feature of the XM971 van, which is useful for HEMP shielding, is the 0.135-in.-thick aluminum floor.

The MEP to be employed is assumed to conform to the description in various Army Manuals[5-8] and the draft TM5-6115-365-15, previously mentioned. The two generator units will be electrically connected in the AN/MJQ-10A configuration through a switch box as described in the draft TM, chapter 28. Commercial power is a planned alternative power source.

---

[5]TM5-6115-365-15, Organizational, DS, GS and Depot Maintenance Manual including Repair Parts and Special Tools List, Generator Sets, Gasoline and Diesel Engine Driven, Trailer Mounted, including PU 406/M (May 1966).

[6]TM5-6115-465-12, Operator and Organizational Maintenance Manual, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, including MEP-005A (January 1975), including updates through Change No. 2 (14 February 1977).

[7]TM5-6115-465-24P, Technical Manual, Organizational, Intermediate (Field) (Direct Support and General Support) and Depot Maintenance Repair Parts and Special Tools List, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, including MEP-005A (February 1977).

[8]TM5-6115-465-34, Intermediate (Field) (Direct and General Support) and Depot Level Maintenance Manual, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, including MEP-005A (January 1975).

The actual power cables to be used and the cable routing configuration between the MEP and the van is uncertain. All cables, in the selection list provided with the DAS3 RFP, are unshielded. A minimum of 40 m is specified for the distance of the MEP from the van.

The HEMP assessment assumes that the requirements included in the Specifications for DAS3[2] will be met by the selected contractor. All EMI, EMC, and general electromagnetic shielding requirements are particularly important. Other specifications[2] considered particularly relevant to HEMP damage and upset protection are the following:

> page 15, section 3, subsection 3.1.5.4:
> "a. Protected Circuits. Voltage surge suppression devices shall be provided on each data/voice circuit to protect equipment and personnel against lightning and electromagnetic pulses. EMI suppression devices shall be provided to meet requirements of paragraph 3.3.2."
>
> page 37, section 3, subsection 3.3.9.1:
> ". . . Power lines shall be filtered on all three phases and neutral, using appropriate EMI suppression filters having attenuation characteristics greater than 60dB over the frequency range of 14kHz to 1GHz."
>
> page 37, section 3, subsection 3.3.9.3:
> "Power Protection. If required, appropriate devices shall be provided to completely protect all variations in prime power which are beyond the limits as contained in MIL-STD-1332 for the type of power used. The system shall also be protected against a power outage to preclude damage to the equipment."
>
> page 55, section 3 attachment, subsection 1.3.3.9:
> "Power Fail Protection. Upon sensing a change in voltage or line transient which is unacceptable to the operatable range of the equipment, the system shall generate an interrupt on the highest priority level. Sufficient filtering shall exist within

[2]Specification for the Decentralized Automated Service Support System DAS3, Tactical Management Information Systems Project Management Office (February 1978).

power supplies to permit the computer to save all data necessary to permit the operator to initiate a restart to continue program execution at the point at which the interrupt occurred or at the last available check point."

page 49, section 3 attachment, subsection 1.2.2.1: "h. Shall prevent application programs from executing privileged instructions."

page 49, section 3 attachment, subsection 1.2.2.1: "i. Shall provide detection of defective memory segments and a procedure for processing user programs in the remaining memory segments."

page 49, section 3 attachment, subsection 1.2.2.1: "j. Shall provide detection and bypassing of defective disk and tape areas."

page 54, section 3 attachment, subsection 1.3.3.1: "Hardware facilities shall provide memory protection capability."

page 62, section 3 attachment, subsection 1.3.4.7.1: "Error detection provided by the hardware."

5. LIMITATIONS OF HEMP ASSESSMENT

The preliminary nature of the results of this HEMP assessment is due to several limitations. These limitations are (1) lack of specific information about the ADPE and installation procedures, (2) lack of definition of final type and configuration for power and signal cables, and (3) lack of experimental data on HEMP energy likely to be coupled to system cables and likely to penetrate into the inner van environment (zone 1).

The confidence of the predicted HEMP survivability of the ADPE to damage and upset cannot be improved unless further analysis is performed to relieve one or more of these limitations. The survivability of the MEP cannot be predicted based on the information available for this study. Testing is necessary for determination of the MEP survivability.

Knowledge of the specific ADPE and installation procedures is important for several reasons. First, the

threshold levels at which damage will occur in ADPE can vary widely. Only after examining the ADPE circuit schematics and wiring interconnection diagrams can one more accurately determine actual damage threshold levels. At minimum, such information would insure that no unusually sensitive circuitry exists.

Second, further ADPE and installation information is important in order to allow determination of how rigorously the specifications stated in the DAS3 RFP[1,2] are met. Some of the specifications do not relate directly to HEMP protection but are useful for that purpose. Examination of circuit schematics, wiring diagrams, and installation procedures would reveal whether protection is provided to the degree expected by this initial HEMP assessment.

Third, one needs to know the exact circuitry which terminates the power and signal cables to allow more accurate prediction of HEMP energy coupled to the cables.

Fourth, examination of actual fault-tolerance procedures is necessary to assure adequacy of the DAS3 plan for HEMP-upset protection.

The lack of information concerning type and configuration of power and signal cables is a limitation because this information is essential for prediction of the HEMP energy coupled to these cables. With specific information about the cables and the circuitry that terminates these cables at the van end, HEMP tools can be applied to greatly enhance the accuracy of predicted coupled energy levels and frequencies.

Testing is always needed to verify the adequacy of HEMP hardening measures and predicted HEMP survivability conclusions. This is due to the unfortunate fact that presently available HEMP prediction tools have not been refined to a satisfactory level of accuracy. The primary weakness in present tools is in the area of prediction of coupling between the HEMP environment and penetrators. For

---

[1]RFP, Solicitation No. DAHC26-78-R-0001, Automated Data Processing Equipment, Decentralized Automated Service Support System; A Mobile, Van-Mounted Management Information System (17 May 1978).

[2]Specification for the Decentralized Automated Service Support System DAS3, Tactical Management Information Systems Project Management Office (February 1978).

DAS3, this specifically limits the prediction of coupling to cables external to the van and to cables internal and external to the MEP.

For DAS3, a system-level test, where the system or system components are subjected to a simulated HEMP environment, is needed if a high-confidence conclusion is desired or if any survivability statement is desired for the MEP. Either a small- or moderate-effort test could be conducted depending on the thoroughness and accuracy required (see sect. 8).

6. RECOMMENDED HARDENING MEASURES

The hardening measures discussed in this section are considered necessary, in addition to RFP specifications, for DAS3 survivability to HEMP. The predicted survivability of the DAS3 ADPE depends on proper implementation of all these measures.

6.1 TPD's at Power and Signal Entry Panels

It is essential that TPD's be installed on all conductors which penetrate the XM971 van walls. This includes all power and signal cable conductors as well as any other conductors associated with external cable runs. Ground conductors must be protected just as conductors which carry power and signals.

DAS3 RFP specifications contain various requirements for transient protection as discussed in section 4. The specifications include specific requirements for voltage-surge suppression on each data/voice circuit and filtering on power conductors (all three phases and neutral). Additional terminal protection is likely to be required to meet the other more general transient and power-failure protection requirements. TPD's which are installed to meet these specifications should be made to withstand expected HEMP levels as well.

Ideally, TPD's (including filters, surge suppressors, and other devices) should be installed directly at entry panels on the external side of the van wall. Grounding of such devices should be made to the external surface of the van wall. This will confine transient currents to the outside surface of the van walls because of

the "skin effect" principles. One publication[10] provides the following example HEMP spark-gap specification.

(1) Application--The protector will be used on an ac power line. The line potential shall be 120 Vrms maximum, 60 Hz ac, with a source impedance of 0.3 ohms.

(2) dc breakdown voltage--350 V minimum, 490 V maximum.

(3) Response time--4 ns maximum with a voltage rate of rise of 5 kV/ns or greater. The response time is defined as the time of application of the voltage to the time when the gap "fires" and the voltage across it no longer increases (see fig. 2).

(4) Transient pulse--The maximum line potential shall be specified as in figure 3 with a source impedance of 6 ohms minimum and a load impedance of 3 ohms minimum resistive.

(5) Extinguish criteria--The gap shall extinguish and not retrip more than once, with the retrip duration not to exceed one-half cycle of the line current, when initiated by the proper trigger pulse.

(6) Operational life--The part shall conduct 10 current pulses as specified from the conditions in 4. In addition the part shall conduct 600 of the current pulses resulting from these conditions, except that the transient voltage amplitude is halved.

(7) Isolation resistance--10 megohms minimum.

Particular specifications can be generated for DAS3 once definite information is available concerning actual external power and signal cables and electronic circuits which terminate these cables at the entry panels.

---

[10]C. H. Hart and D. F. Higgins, A Guide to the Use of Spark Gaps for Electromagnetic Pulse (EMP) Protection, Joslyn Electronic Systems (1973).

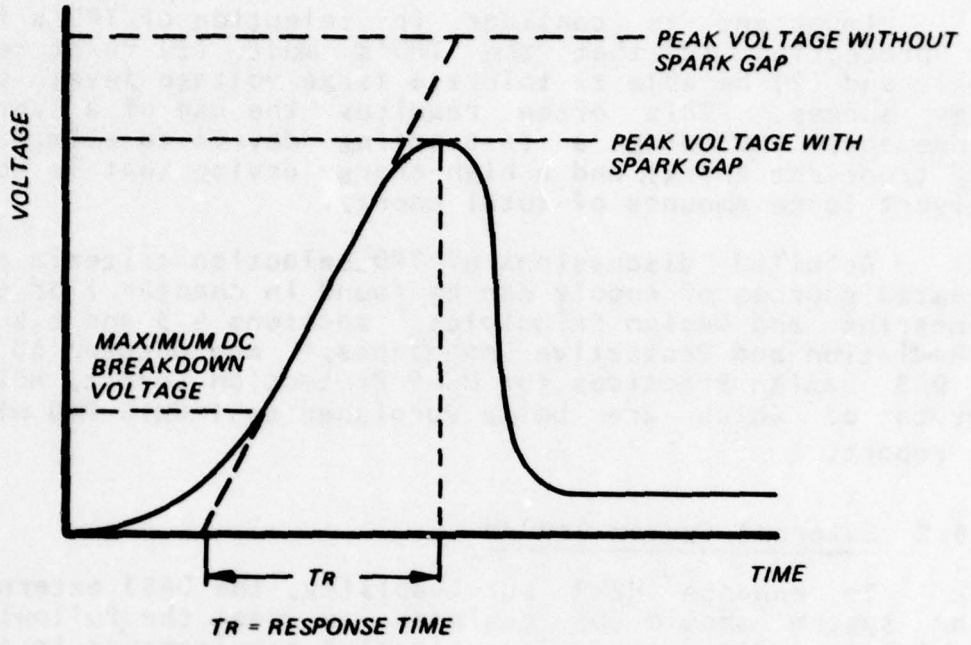


Figure 2. Spark gap response time definition (ref 10).

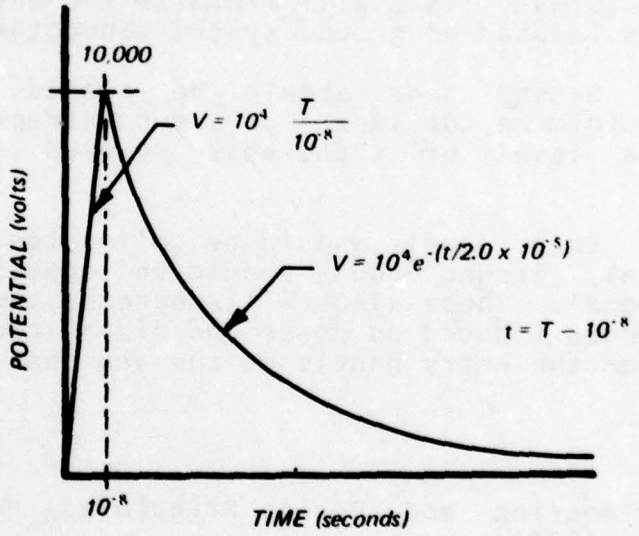


Figure 3. Spark gap pulse potential waveform (ref 10).

Important to consider in selection of TPD's for HEMP protection is that the TPD's must (1) react very quickly and (2) be able to tolerate large voltage levels and energy surges. This often requires the use of a hybrid arrangement, including a fast-acting device to eliminate early transient energy and a high-energy device that is able to divert large amounts of total energy.

Detailed discussions of TPD selection criteria and suggested sources of supply can be found in chapter 7 of EMP Engineering and Design Principles,[3] sections 4.3 and 4.4 of EMP Radiation and Protective Techniques,[11] and chapter 10 of the DCS Design Practices for HEMP Protection (draft, HDL), excerpts of which are being furnished to TACMIS PMO with this report.

6.2 External System Ground

To enhance HEMP survivability, the DAS3 external ground system should be designed to meet the following criteria in addition to other grounding requirements in the RFP specifications.

(1) The number of connections to the ground system from cable shields, entry panels, and the van body should be kept to a minimum. This will minimize the adverse effects of transients induced on ground system conductors.

(2) Ground rods should be placed close to the system to minimize the length of ground straps. This will minimize the level of transients coupled to the ground straps.

(3) Entry panels should be collocated. If this is not practical, ground rods should be located directly at each entry panel. These steps will decrease the possibility that transients induced on power and signal conductors will travel between the entry panels on the van shell.

---

[3]EMP Engineering and Design Principles, Bell Telephone Laboratories (1975).

[11]L. W. Ricketts, J. E. Bridges, and J. Miletta, EMP Radiation and Protective Techniques, John Wiley & Sons, New York (1976).

(4) All ground straps and other conductors should be at as low an impedance as possible. The intent is to provide transients with a lower impedance path to ground than to the cables or van structure.

6.3 Installation of Power and Signal Entry Panels

The power and signal entry panels must be properly installed to avoid degrading the overall shielding effectiveness otherwise provided by the XM971 semitrailer van. The intent is to avoid providing any opening through which electromagnetic radiation can penetrate the inner van environment. The entry panels as installed should provide 60 dB of attenuation to the HEMP environment. A detailed discussion of apertures and bonding procedures is provided by Campi.[12,13] Important criteria from these references are described below.

The basic entry panels should consist of a conductive metallic material. The panel material should be the same as that of the mating surface, although this is not required. Use of similar materials enhances the bonding properties of the joint and the resistance to electrolytic degradation of the bond.[13] No unintentional holes or gaps should exist in the panels.

Any unused holes in the panels should be tightly sealed with metal plates or caps of the same material as the surface they contact. These seals may be welded, riveted, bolted, or screwed in place, as desired. Conductive gasketing[12] is desired for other than welded joints when the mating surfaces do not make good contact over the entire mating surface. Gasketing is also recommended for connecting pieces which will be removed for service or other use. All mating surfaces should be sanded bare. Corrosion inhibitors should be applied to mating surfaces which are subject to corrosion.[13] This should not be necessary where similar materials are joined. For large holes, the bolt, weld, or rivet spacing should be a maximum of 3 in.[12] The pressure applied between the mating surfaces must be at least 20 psi.[12]

---

[12]Morris Campi, Survey and Review of Aperture Shielding for EMP/RFI Fields, Harry Diamond Laboratories, HDL-TM-78-25 (December 1978).

[13]Morris Campi, Survey and Review of Building Shielding to Electromagnetic Waves from EMP, Harry Diamond Laboratories, HDL-TM-78-23 (November 1978).

Entry panels should be firmly secured to van walls. Mating metal surfaces should be bare and must overlap. Conductive gasketing is recommended for uneven mating surfaces or when the panels are expected to be removed for service access. Corrosion inhibitors should be considered for mating surfaces which are subject to corrosion. A maximum 3-in. bolt spacing (or distance between rivets or weld spots) should be used. Installation of the panels should be tight enough to compress gasketing around the entire perimeter of the opening. Mating surfaces should be joined with a pressure of at least 20 psi.

6.4 Installation of Air Conditioners and Vents

Installation of air conditioners into the XM971 van front wall could degrade the potential shielding effectiveness, as would any aperture in a shield boundary. Installation of the air conditioners should be in a manner consistent with the goal of 60-dB shielding effectiveness for the overall van inclosure to plane waves in the frequency range from 10 kHz to 1000 MHz. This requires elaboration on or additions to installation specifications in the RFP in two areas. First, no gap should be allowed around the periphery where the air conditioner mounts in the van wall. Second, electromagnetic shielding should be placed over all exhaust and intake vents.

The joint where the air-conditioner units mate with the holes in the van front wall should be tightly sealed so as to inhibit the leakage of electromagnetic radiation into the inner van environment. Since the air conditioners must be removable for servicing or replacement it is presumed that they will be bolted in place. A maximum 3-in. bolt spacing should be used. Conductive gasketing[12] should be used if frequent disassembly is expected or if mating surfaces do not make smooth continuous contact around the entire periphery of the opening. When the gasketing is installed a positive pressure should be applied to it so that it is compressed around the entire periphery of the opening.

Screening should be placed over all vent openings. Alternative types and sources acceptable for HEMP shielding are discussed by Campi.[12] A honeycomb shield is probably the best choice, as the following excerpt from Campi[12] indicates:

---

[12]Morris Campi, Survey and Review of Aperture Shielding for EMP/RFI Fields, Harry Diamond Laboratories, HDL-TM-78-25 (December 1978).

"All inlet and/or outlet apertures for ventilation or pressurization should be designed for EMP suppression. In many cases, shielding mesh screens introduce excessive air resistance, and sometimes greater shielding effectiveness may be needed than they can provide. Although louvered openings are generally used for cooling air circulation, they are extremely poor for EMP/RFI integrity because of their long, narrow gaps. If good shielding or strength is required, but weight and space are not critical, honeycomb panels may be used. The honeycomb attenuates fields both by reflection and by the attenuation properties of waveguides below cutoff. The honeycomb is essentially a screen of waveguides, and its attenuation is a function of the cross-sectional size and length of the waveguides, the number of waveguides per area on the panel face, and the material of which the honeycomb is made. For example, steel honeycomb is very effective for electric field shielding; attenuation of over 100 dB can be readily obtained over the entire EMP frequency range. For comparable magnetic field attenuations, thick honeycomb made of iron or magnetic stainless steel must be used."

For installation of honeycomb shielding over vents, the joint between the shield and the vent should make a good electrical bond.

6.5 No Additional Apertures or Penetrators

In the construction and assembly of DAS3, additional apertures or penetrators should be avoided. An untreated or improperly installed aperture or penetrator can seriously degrade the shielding effectiveness provided by a shield boundary. A van shelter which potentially provides 60 dB of shielding effectiveness can be rendered totally ineffective by the haphazard incorporation of apertures and penetrators.

Some apertures and penetrators are invariably necessary. They should, however, be limited to the minimum. The required penetrators for DAS3 include the power cable, data, and voice signal lines. The apertures include side and rear van doors, air-conditioner installation holes and vents, and installation holes for the power and signal-entry panels. Each of the planned DAS3 apertures and penetrators has been addressed in this initial HEMP study and appropriate treatments have been proposed. Any apertures or penetrators which are added to the DAS3 design must each be specifically examined for possible detrimental effects to the expected HEMP protection.

6.6 Standard Requirement for Closed Doors

The standard operating procedures for DAS3 must require that all van doors be kept shut as much as possible. Whenever any one of the doors is open, the shielding effectiveness of the XM971 semitrailer van is predicted to be well below the level required for damage protection against the HEMP environment. DAS3 is considered vulnerable to HEMP whenever any door is not completely closed and latched.

It is recommended that DAS3 operations documentation clearly reflect this requirement. It is further recommended that an appropriate sign be prominantly placed next to each door.

Maintenance documentation should also require that all doors be checked periodically and adjusted if necessary to assure that they seal properly when closed and latched (see also sect. 6.7). In order to provide a proper electromagnetic seal, positive pressure must be applied to compress the gasketing around the entire perimeter of the door.

If it is decided that doors cannot be effectively kept closed, or if HEMP hardness is required at all times including during open-door periods, then a double door or shielded vestibule arrangement is necessary (see sect. 7.3).

6.7 Hardness-Assurance Procedures

Routine required maintenance procedures should be established whereby the continued effectiveness of HEMP protection measures can be assured. Maintenance documentation should require periodic examination or testing of all important HEMP-protection measures and should call for appropriate repair, replacement, or adjustment as necessary.

As a minimum, inspection or testing should be performed to verify the following.

(1) Grounding systems
    (a) proper installation
    (b) good electrical continuity of all connections and wiring

(2) Van integrity
   (a) no openings or loose members in van walls, floors, or ceiling
   (b) all metal grills, filters, etc, properly installed
   (c) all removable panels tightly and properly installed
   (d) all unused connectors or holes in signal and power entry panels properly sealed or capped

(3) Shielding
   (a) all cable shields (if any) properly installed and in good physical condition
   (b) door seals in good physical condition (i.e., no breaks, not crushed or otherwise distorted)
   (c) door seals and mating surfaces clean and bare for good electrical contact (i.e., no dirt, grease, or nonconductive paint)
   (d) proper closing of doors; when closed and latched, doors should apply a positive pressure on the electromagnetic gasketing around the entire perimeter of the door in such a way as to slightly compress the gasket

(4) TPD's
   (a) proper installation of all TPD's
   (b) proper electrical operation of all filters and transient-suppression devices or circuitry

All the above checks (except 4b) should be performed routinely at frequent intervals (at least once a year) and also following any physical movement of the equipment. All the above checks except the last (4b) can be performed by operations personnel.

Some concern has been raised by TACMIS PMO and others that the force needed to close and latch the van doors might be excessive. A specification for the S-280 shelter, MIL-S-55286C(EL) (pending approval to supersede MIL-S-55286B(EL), dated 22 September 1975), addresses this question for that shelter. This new S-280 specification includes a requirement for a modification kit for RFI protection (MK-1079) which is intended to bring HEMP shielding up to a 60-dB level.

The proposed specification requires (in sect. 3.7.2) that the door latch torque not exceed 15 ft-lb maximum when the RFI kit is not installed or 30 ft-lb when the kit is installed. Testing requirements (sect. 4.6.16 of specification) state: "Torque measurements shall be made using a torque wrench fitted with an adapter which seals over the outside door handle and in line with the shaft centerline. The door shall then be opened and closed using the torque wrench. Measurements shall be made over the entire working range of the latch in both cases."

7. SUGGESTED OPTIONAL HARDENING MEASURES FOR ADDED CONFIDENCE

This section contains a discussion of optional HEMP hardening measures considered desirable for DAS3. These measures are suggested as means for providing additional margins of protection or added confidence. Any of these measures which can be implemented without cost impact should be implemented.

Two of the measures, gasketing around MEP access doors and shielded power cables, are possible hardening measures to assure hardness of the MEP, although these are not known to be necessary or adequate based on this study. Various of these optional hardening measures could be needed if future analysis reveals deficiencies.

7.1 Gasketing around MEP Access Doors

Installation of conductive gasketing around each of the access doors on the MEP units would significantly reduce HEMP-induced field levels within the MEP-005A housing. This would reduce transients coupled to internal cable harnesses. Experimentation with such shielding was performed for an HEMP assessment of a similar 15-kW generator (see sect. 1.2.3). The results of that experiment were good although the shielding technique used is not recommended as it is not sufficiently durable.

Shielding of the MEP access doors and shielding of the main external power cables (see sect. 7.6) are top-priority and very effective measures for enhancing the HEMP hardness of the MEP-005A if hardening is considered necessary.

3.4 Fault Avoidance/Fault Tolerance

The techniques used to combat HEMP-induced problems can be divided into two broad categories: fault avoidance and fault tolerance. Fault, as used here, refers to any abnormal condition of hardware, software, or data that may cause a deviation in the information-processing behavior from the expected and desired sequence. A fault may be a component failure (damage) or may be any of the various types of upset conditions.

Fault avoidance is an arrangement whereby a system, subsystem, or circuit avoids a fault condition in spite of the presence of a disturbance (such as an HEMP-induced transient). Fault avoidance includes installation of hardware to reduce a transient to an acceptable level or designing the hardware so that the system is insensitive to the transient or both. This includes (1) installation of TPD's (surge-suppression devices and filters), (2) proper grounding, bonding, and shielding, and (3) design of transient-resistant circuits.

Fault tolerance is an arrangement whereby a system, subsystem, or circuit continues to operate in the expected manner in spite of a fault. Electrical circuitry or other hardware, software, or operating procedures are specially designed or supplemented so that faults are detected and are either ignored, corrected, or otherwise mollified.

Fault avoidance includes all the common HEMP-hardening measures recommended for general electronic systems for protection against damage. Fault-avoidance techniques are implemented in hardware. Fault-tolerance measures can be implemented in hardware, software, standard operating procedures, or combinations of these. Fault-tolerance measures can be used to provide the additional protection needed by computer systems and equipment in order to tolerate upset faults (see sect. 3.5 and 3.6 for further discussion of fault-avoidance and fault-tolerance techniques).

3.5 Design Guidelines for Fault Avoidance

The purpose of fault avoidance is to design a system, subsystem, or circuit so that a fault is prevented from occurring. Fault avoidance includes installation of hardware to reduce a transient to an acceptable level,

designing the hardware so that the unit is insensitive to the transient, or both. This includes (1) installation of TPD's (surge-suppression devices and filters), (2) proper grounding, bonding, and shielding, and (3) design of transient-resistant circuits.

Fault avoidance includes all the common HEMP-hardening measures recommended for general electronic systems for protection against damage. Fault-avoidance measures are implemented in hardware, unlike fault-tolerance measures which may be implemented in hardware, software, operating procedures, or combinations of these. Fault-avoidance and fault-tolerance measures together can protect against upset. Fault tolerance is not an effective technique for damage protection.

The general fault-avoidance types of hardening measures are discussed elsewhere and will not be further defined here. What is important to discuss is the need for fault-avoidance measures and the extent that they should be installed for ADPE. With a system that includes ADPE, the designer must employ fault-avoidance measures as a first line of defense. It is extremely difficult to harden most ADPE configurations with fault-tolerance measures alone. Invariably, the most cost-effective approach to total HEMP hardness involves a good fault-avoidance scheme supplemented with fault-tolerance measures as needed.

A comprehensive implementation of normal hardware hardening measures is required if transients are to be reduced to reasonable levels within the system environment. Highly desirable is a good overall shield inclosure around the overall system, plus some attempt at shielding individual system elements within zone 1, thus providing two levels of shielding between sensitive circuitry and the HEMP environment. As a minimum, one level of shielding is required. The fault-tolerance alternative to hardening would require many redundant circuits and components, for damage protection alone, and could not be as cost-effective.

In addition to shielding, all penetrators and apertures must be treated to at least some degree. Some form of HEMP TPD's (filters, surge suppressors, or both) should be applied to all conductors which penetrate the overall shield boundary. If a system has an overall shielded inclosure (zone 0/1 boundary), then as a rule, it is by far the least expensive option to treat possible leaks

7.2 Internal Van Ground

A floating ground system, grounded to earth at one point, would be optimum from an HEMP-protection standpoint for the internal van environment. This is desired but not required. This type of ground system would be the most effective means of isolating the ADPE from transients induced on the van external walls, external cables, and external ground system.

Such a ground system could consist of a conducting false floor raised perhaps 6 in. off the van bottom. This floor would be isolated electrically from the van structure except at a single point. A central very-low-impedance ground strap would connect directly from this false floor to ground at the entry panel. All equipment would be well grounded to equipment racks which would be well grounded to this floating ground floor at their bases. Interrack cables could be routed beneath the floor for convenience.

7.3 Vestibule for Van Entrance

A vestibule arrangement could serve to block HEMP energy from entering a van through an entrance doorway. This measure could be used as an alternative to keeping van doors closed or could be used for added protection where inadequate shielding is provided by the existing door. When used in combination with two shielded doors, maximum protection would be attained.

Figure 4 shows several possible vestibule arrangements which take advantage of the waveguide below cutoff principles described by Campi.[12] The predicted shielding effectiveness (S), in dB, provided by an open, rectangular-cross-section vestibule with depth c and maximum opening size b is calculated as follows:

$$S = \frac{27.3c}{b} .$$

---

[12] Morris Campi, Survey and Review of Aperture Shielding for EMP/RFI Fields, Harry Diamond Laboratories, HDL-TM-78-25 (December 1978).

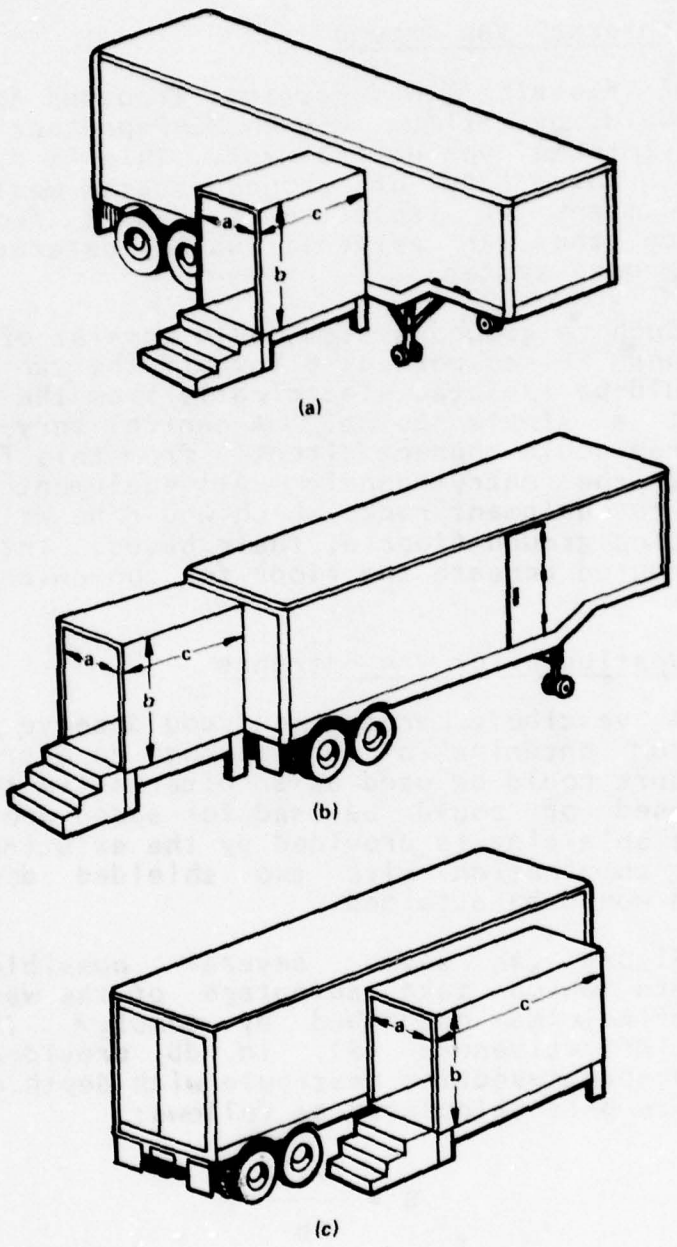


Figure 4. Three examples of vestibule configurations for a single van.

failures. The same repair procedure as described for the first damage class must be performed to restore the system to its complete ready state. This class of failure may be very serious if the time required to repair the failure is long; in this case, it becomes highly probable that a subsequent failure, leading to total system failure, will occur before the repair. Further, if the system is required to operate in an environment of multiple HEMP events, then the type of failure may occur repeatedly in a relatively short time, resulting in the loss of all redundant units. Further, if the redundant units are the hot or warm backup type, and the failure is due to a transient on a power line or other active cable or bus, all units might be lost simultaneously.

The upset case is divided into four classes as shown in table IV. The first class is the most serious and refers to the situation where a fault has occurred and has gone undetected. Since the fault is undetected, the computer system and operations personnel are unaware of the problem and can take no corrective action. There is no solution if such a fault occurs. A typical example might be the miscommunication of information, causing faulty results to be generated. This class of upset can be extremely serious depending on the nature of the system's mission. In a communications switch, for instance, it might mean simply the loss of a call or information packet. On the other hand, it might mean the distortion of critical information like a routing table. This class of fault points out the important fact that the highest priority requirement for any fault-tolerance measures employed is that they must be able to detect the fault they are intended to alleviate.

The second upset class is generally less serious than the first in that the upset is detected, so at least the system is aware that faulty performance may result. This class is still extremely undesirable since the fault is not correctable. As an example, say the system has over-written irreplaceable data on a storage unit or has lost irreplaceable call routing information. Certain functions are lost with no chance for correction or reproduction. If key operation information is lost on a storage device or in memory, then that operation of the system is lost. This event may not seem likely, but it is possible. It points to the necessity for maintaining good redundant copies of all system-critical software and data.

The third and fourth upset classes deal with detectable and correctable faults. In both cases operation can continue after a delay during which the correction or restoration is performed. These classes are the least serious. Examples of automatic fault detection/correction are the numerous error-checking schemes employed by most computer systems for data transmission and for storage and retrieval of information. Many machines and much software also employ various types of checking techniques to some extent in computations. If the detection and correction process is automatic, then the only loss is in terms of degradation of system throughput.

An example of an automatic detection/correction process might be a communication network control node that identifies a transmission error and requests from the sender a retransmission. Such a delay is usually acceptable and in fact common, unless such errors occur to the extent that system throughput cannot keep up with the network load demands. If restoration requires human intervention, then the delay incurred is generally much longer. Such a delay would not be acceptable for a system mission requiring real-time, continuous operation.

It is important to note a potential problem in tolerating HEMP-induced upsets. HEMP may cause massive parallel upsets of many types. These upsets may be interdependent and may overload the system's ability to carry out designed fault-tolerance procedures.

The mission impact of the above classes depends on the nature of the mission. It is up to the system designer to determine whether his system's mission can tolerate various types of failures and to design the system so that only tolerable failures will occur. It is of course inevitable that failures and upsets of some nature will occur. It is possible, however, through use of HEMP hardening measures, including good fault-tolerance techniques, to attain any degree of reliability required. With a thorough analysis of the system's mission and an understanding of the hardening options, the designer can determine the necessary hardening measures and can minimize the design cost.

The shielding effectiveness is greater than or equal to that calculated by the above equation up to the cutoff frequency. The cutoff frequency (F), in MHz, for such a vestibule with maximum opening dimension b, in inches, is calculated as follows:

$$F = \frac{5900}{b} .$$

The DAS3 side door is 37.12 in. wide and 76.06 in. tall. For an appropriate vestibule (without an additional door), 48 in. wide and 78 in. tall, the shielding effectiveness for various depths is given in table VI. The cutoff frequency for a 78-in.-tall vestibule is 75.6 MHz.

TABLE VI. SHIELDING EFFECTIVENESS OF A 48 BY 78 in. VESTIBULE WITH OPEN END

Depth (ft)	Depth (in.)	Shielding effectiveness (dB)
4	48	16.8
6	72	25.2
8	96	33.6
10	120	42.0
12	144	50.4
14	168	58.8
15	180	63.0
16	192	67.2
18	216	75.6
20	240	84.0

If a door were used on the entrance to the vestibule then the combined shielding effectiveness of the door and vestibule assembly would be the sum of the shielding effectiveness provided by the vestibule, as given in table VI, and the shielding effectiveness of the door.

For example, assume (1) a normal van door that is open, (2) a properly constructed and installed 48 by 78 by 96 in. vestibule, and (3) a moderate-quality 30-dB closed door on the vestibule. The shielding effectiveness of the entryway would be 63.6 dB (33.6 + 30). Such an entryway would adequately support a van with an effective 60 dB of shielding. If the inner door (normal van door) were also closed and it provided 30 dB of protection, then the shielding effectiveness of the entryway would be 93.6 dB.

As another example, the 4-ft-deep vestibule from table VI, with 40-dB inner and outer doors, would provide 16.8 dB with both doors open, 56.8 dB with one door closed, and 96.8 dB with both doors closed. One door closed would provide nearly enough attenuation to avoid degrading the maximum expected 60 dB provided by the XM971 semitrailer van.

The requirements for construction of a vestibule for a 60-dB application[12,13] are as follows: The floor, roof and walls must be of metal. Any common construction metals could be used. Any thickness adequate for structural strength would be sufficient. The pieces making up the walls, floor, and roof should, in general, be as large as possible. If multiple panels are used, a bolt or rivet spacing of 3 in. or less should be used. A similar bolt spacing is required for all other mating joints as well. Where the walls join the roof and floor, one mating piece should be flanged (bent at 90 deg) so that it can overlap the other. This latter criterion is not necessary, but is desirable. Alternatively, both mating pieces could be connected to a metal structural support so long as no gap or opening is allowed. The most critical mating connection is at the van. Here again a flanged arrangement would be best with a 3 in. or less bolt spacing. A conductive gasket[12] should be used at the van/vestibule joint to assure a good bond. The gasket is especially important here since the connecting surfaces are not likely to mate tightly and since this joint will be disconnected often for transit.

There is no reason that a vestibule as proposed above could not be disassembled, stowed on, in, or under the van for transit, and reassembled at a new site. Use of an adequate vestibule could totally eliminate possible problems because of an inability to meet the proposed standard requirement for closed entry doors (see sect. 6.6).

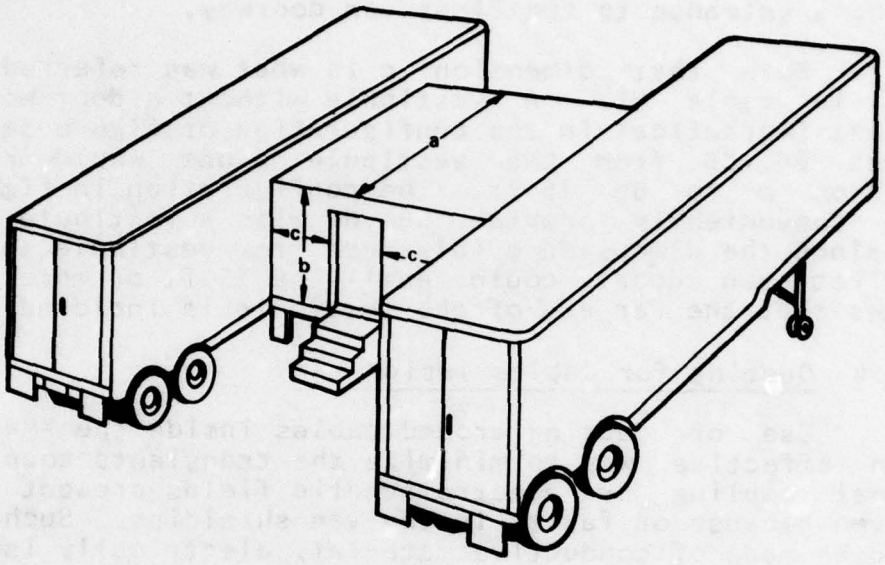
Figure 5 provides two examples of the use of a vestibule for connecting two vans. It is common with many Army systems (such as the Combat Service Support System) to configure vans side by side, end to end, or side to end, and

---

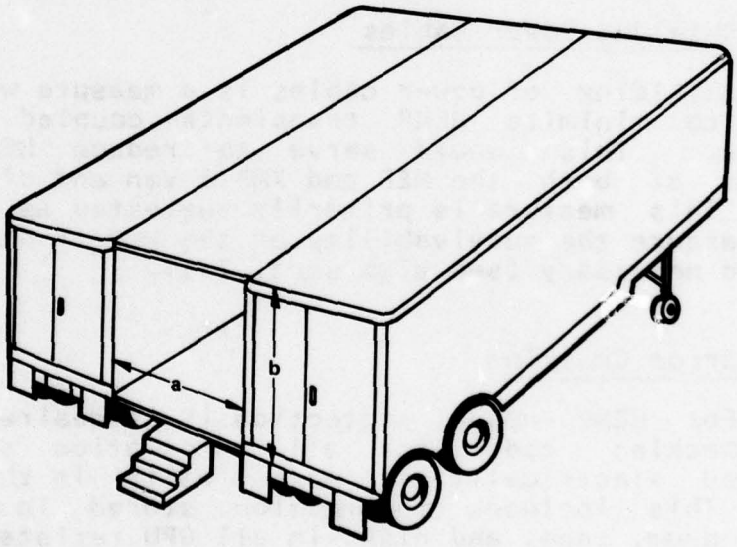
[12]Morris Campi, Survey and Review of Aperture Shielding for EMP/RFI Fields, Harry Diamond Laboratories, HDL-TM-78-25 (December 1978).

[13]Morris Campi, Survey and Review of Building Shielding to Electromagnetic Waves from EMP, Harry Diamond Laboratories, HDL-TM-78-23 (November 1978).

connect doorways with some sort of walkway. No system, however, is known to use a covered walkway which is a good electromagnetic shield.



(a)



(b)

Figure 5. Two examples of vestibule configurations for two vans.

The dimensions a, b, and c in figure 5 correspond to those used in the previous equations of this section for calculating effectiveness and cutoff frequency. Dimension c is not shown in figure 5b, where it is the distance from the vestibule entrance to the first van doorway.

Note that dimension c is what was referred to as depth in table VI. A vestibule without a door would be somewhat impractical in the configuration of figure 5a since to get 60 dB from the vestibule alone would require dimension c to be 15 ft. The configuration in figure 5b could conveniently provide 60 dB with a vestibule and no door since the dimension c (distance from vestibule entrance to first van door) could easily be 15 ft or more. This assumes that the far end of the vestibule is inclosed.

7.4 Ducting for Cables Inside Van

Use of ducting around cables inside the XM971 van is an effective way to minimize the transients coupled to internal cabling by electromagnetic fields present inside the van because of faults in the van shielding. Such ducts should be made of conductive material, electrically isolated from the van shell, and grounded to the internal system ground.

7.5 Shielded Power Cables

Shielding of power cables is a measure which could be used to minimize HEMP transients coupled to power conductors. This would serve to reduce HEMP-induced transients at both the MEP and XM971 van end of the power cables. This measure is primarily suggested as a possible means to assure the survivability of the MEP if hardening is considered necessary (see also sect. 7.1).

7.6 Error Checking

For HEMP upset protection it is desirable to use error checking codes for all information stored and transferred electrically or magnetically in the computer system. This includes information stored in memory, on magnetic drum, tape, and disk, in all CPU registers, in all peripheral control registers, and in data transfer buffers. Error checking is also desirable for all information transfers both between CPU and all peripherals and between

the communications controller and remote terminals. Error checking ultimately would also include verification of execution of machine instructions.

Error checking should be used in conjunction with the other planned DAS3 fault-tolerance measures to protect against HEMP-induced upsets. Error checking is considered a most effective means to detect upsets. Extensive error checking as outlined above would nearly, if not completely, solve the upset detection problem (see sect. 1.2.1).

7.7 EMP Detector

The concept of an EMP sensor has considerable merit for fault-tolerance applications, although such a scheme is not known to have ever been used for protection of ADPE. Such a scheme[11] is proposed as follows:

"Threat-specific circumvention techniques generally involve the detection of a nuclear event by an EMP sensor supplemented by some other type of sensing system to suppress false triggering. Such a supplementary sensor might be achieved by means of a photocell. . . . A sensor of very great bandwidth detects the EMP transient and employs a very-large-bandwidth cabling system to provide an off gate for the main computing system, which is located in a heavily shielded, underground shelter. The EMP from the burst as it diffuses into the heavily shielded enclosure is delayed in time because of the low-pass frequency characteristics of the electromagnetic shield. The computational circuits are designed so that they can be temporarily desensitized in such a way that the EMP pickup, if it occurs, will have little effect."

A hardware implementation would probably be required to carry out the deactivation of the computer system, since high speed is required. Any further recovery process could be implemented in hardware, in software, or as an operator procedure. A possible implementation of the EMP sensor idea which could be used for DAS3 upset toleration is the following. The occurrence of an HEMP event could be determined by the detection of multiple or massive upsets in the system. An automatic or manual rollback and restart procedure could then be initiated.

---

[11] L. W. Ricketts, J. E. Bridges, and J. Miletta, EMP Radiation and Protective Techniques, John Wiley & Sons, New York (1976).

8. PROPOSED FOLLOW-UP HEMP ASSESSMENT

Additional study and a limited HEMP simulation test are recommended to verify the predicted HEMP survivability of the DAS3 ADPE, including the recommended hardening measures, and to insure survivability of the DAS3 MEP.

The prediction that the DAS3 ADPE is hard to the HEMP environment has only low confidence because of the several limitations of this study, described in section 5. To enhance the confidence of this conclusion and verify the HEMP survivability of the ADPE, for both damage and upset, further study is proposed to include examination of (1) the actual ADPE circuitry, (2) the manner in which it is installed in the semitrailer van, (3) actual implementations of fault-tolerance procedures, (4) the selected power and signal cables, and (5) the adequacy of measures used to meet important HEMP-related specifications in the RFP (see sect. 4).

An HEMP simulation test of DAS3 is also recommended as a final verification of the predicted hardness of the ADPE to HEMP-induced damage. Test verification of the upset hardness of the ADPE is not recommended. Verification testing of ADPE upset involves considerably more effort than a test to assess damage hardness. Such expense is not considered justifiable in view of the DAS3 mission and the nature of the planned fault-tolerance techniques.

An HEMP simulation test is necessary to reach an adequate HEMP-survivability conclusion for the DAS3 MEP. Testing would provide data on the HEMP energy coupled to MEP internal and external cables, to be used to conduct detailed circuit analysis of the MEP-005A circuitry.

The proposed follow-up HEMP study of DAS3 would require an estimated three man months total by one or more HEMP-experienced engineers and should include the following tasks.

(1) refine predicted HEMP coupling to power and signal cables

(2) determine the range of damage threshold levels for ADPE (insure that no unusually sensitive circuitry is present)

(3) determine whether protection measures called for in the RFP and in the initial HEMP study are implemented to the degree required for HEMP protection

(4) determine whether actual implementation of fault-tolerance measures, as required by the RFP, is adequate for the detection of upsets likely to be induced by HEMP

(5) provide an enhanced DAS3 HEMP survivability conclusion based on the above tasks

Two alternative HEMP simulation tests are proposed to verify the predicted DAS3 ADPE survivability and to assess the survivability of the MEP. The first plan involves testing a configuration consisting of the MEP and XM971 semitrailer van, not including the ADPE, but including external power and signal cables. Either a single MEP-005A generator or an AN/MJQ-10A configuration of dual MEP-005A generators could be used to yield equally good results. The second test proposed involves a test of a complete prototype DAS3 (i.e., same equipment as plan 1, but including final installation of ADPE in the semitrailer).

The second test plan is preferable to the first since it would yield more complete data on the system. The first plan is proposed as an alternative primarily because of the possible unavailability of a complete prototype for testing.

Any HEMP testing should involve equipment which is as similar as possible to planned production systems. Any deviation could seriously degrade the validity of test results. Thus, one should discourage the use of any interim prototype like the ones originally planned to be assembled by Tobyhanna Army Depot.

An HEMP simulation test would consist of deploying the DAS3 equipment in actual physical configurations in the testing area of HEMP field simulation antennas. The system components would be exposed to a simulated HEMP environment at or near the postulated threat level. Two HEMP simulators would be used in different phases of the test to expose the system components to both vertically polarized and horizontally polarized HEMP fields. The DAS3 equipment would be configured in various physical orientations with respect to the antennas, in order to determine worst-case HEMP coupling to the system.

Measurements made during HEMP testing would include voltage and current levels coupled to internal and external cables and field levels induced within the semitrailer van. If the ADPE is included, further voltage and current measurements could be made at points within the ADP system which are (1) at HEMP ports of entry, (2) in cables and circuits near components which are inherently sensitive to damage, or (3) in cables and circuits near circuitry which performs critical functions.

An HEMP simulation test would involve both pre- and post-test analysis. The pretest analysis involves generation of a test plan which includes the physical configurations and orientations to be examined, possible electrical configurations relating to the operating modes of system equipments, and selection of important test measurement locations throughout the system. Post-test analysis must include reduction of the test data into usable form, computer-aided circuit analysis to predict actual voltages and currents at components of interest, and formulation of the survivability conclusion based on test results. Circuit analysis is necessary for two reasons. First, because of the physical size of the DAS3 system and the limitations of the HEMP simulators, it is unlikely that threat-level fields will be provided throughout the system area. This requires that measured data be scaled up to levels which correspond to actual threat. Circuit analysis is then performed to determine how system electronics would perform at those scaled-up levels.

The second reason circuit analysis is required is to allow examination of the safety margins between actual measurements or scaled-up measurements and the damage threshold levels of electronic components or circuits. Such an examination is necessary because of the large statistical variation between damage-failure levels of equivalent semiconductor components.

The proposed HEMP simulation test program would involve the level of effort estimated in table VII.

TABLE VII. PROPOSED TEST PROGRAM EFFORT

Effort	DAS3 minus ADPE	Complete DAS3
Pretest analysis	6 man weeks (professional)	8 man weeks (professional)
HEMP simulator operation (at $6k per week)	3 weeks	4 weeks
Test support	6 man weeks (professional)	8 man weeks (professional)
Post-test analysis	8 man weeks (professional)	16 man weeks (professional)
Final report generation	6 man weeks (professional)	6 man weeks (professional)

LITERATURE CITED

(1) RFP, Solicitation No. DAHC26-78-R-0001, Automated Data Processing Equipment, Decentralized Automated Service Support System; A Mobile, Van-Mounted Management Information System (17 May 1978).

(2) Specification for the Decentralized Automated Service Support System DAS3, Tactical Management Information Systems Project Management Office (February 1978).

(3) EMP Engineering and Design Principles, Bell Telephone Laboratories (1975).

(4) TM9-2330-271-14, Operator's, Organizational, Direct Support and General Support Maintenance Manual, Semitrailer, Van: Electronic 10-Ton, 4 Wheel, Including XM913 (12 May 1972), including updates through Change No. 2 (26 Nov 1976).

(5) TM5-6115-365-15, Organizational, DS, GS and Depot Maintenance Manual Including Repair Parts and Special Tools List, Generator Sets, Gasoline and Diesel Engine Driven, Trailer Mounted, Including PU 406/M (May 1966).

(6) TM5-6115-465-12, Operator and Organizational Maintenance Manual, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, Including MEP-005A (January 1975), Including updates through Change No. 2 (14 February 1977).

(7) TM5-6115-465-24P, Technical Manual, Organizational, Intermediate (Field) (Direct Support and General Support) and Depot Maintenance Repair Parts and Special Tools List, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, Including MEP-005A (February 1977).

(8) TM5-6115-465-34, Intermediate (Field) (Direct and General Support) and Depot Level Maintenance Manual, Generator Set, Diesel Engine Driven, Tactical Skid Mtd. 30 kW, 3 Phase, 4 Wire, 120/208 and 240/416 Volts, Including MEP-005A (January 1975).

LITERATURE CITED (continued)

(9) Report of Test on Radio Frequency Attenuation of Trailer XM703, Miller Trailers, Inc., Electronic Communications, Inc., 4-1160 (6 July 1965).

(10) C. H. Hart and D. F. Higgins, A Guide to the Use of Spark Gaps for Electromagnetic Pulse (EMP) Protection, Joslyn Electronic Systems (1973).

(11) L. W. Ricketts, J. E. Bridges, and J. Miletta, EMP Radiation and Protective Techniques, John Wiley & Sons, New York (1976).

(12) Morris Campi, Survey and Review of Aperture Shielding for EMP/RFI Fields, Harry Diamond Laboratories, HDL-TM-78-25 (December 1978).

(13) Morris Campi, Survey and Review of Building Shielding to Electromagnetic Waves from EMP, Harry Diamond Laboratories, HDL-TM-78-23 (November 1978).

SELECTED BIBLIOGRAPHY OF FAULT-TOLERANCE LITERATURE

Avizienis, A., Fault-Tolerant Computing--Progress, Problems, and Prospects, Proceedings of IFIP Congress 77 (August 1977).

DeVries, R. C., Application of Fault-Tolerant Techniques and Differential Logic to Radiation-Hardened Circuit and System Design, University of New Mexico, sponsored by Air Force Weapons Laboratory, AFWL-TR-77-76 (November 1977).

Fredrick, J. P., Alternative Hardening Measures for Digital Systems Susceptible to Transients (Draft), SRI International (November 1977).

Genin, R. D., Frederick, J., Whitson, A. L., Transient Effects on Computers (Vol I) (Draft), SRI International (April 1977).

Genin, R. D., Frederick, J., Whitson, A. L., Transient Effects on Computers (Vol II) (Draft), SRI International (April 1977).

Graham, W. R., Houston, J. B., Transient Upset Toleration as an EMP Hardening Technique, R & D Associates, sponsored by Defense Nuclear Agency, DNA 3388T, AD787620 (August 1974).

GLOSSARY

ADP--Automatic data processing.

ADPE--Automatic data processing equipment.

AESOP--Army Electromagnetic Pulse Simulator Operations. AESOP is a fixed-site, large-area, high-level HEMP simulator at the Harry Diamond Laboratories' Woodbridge Research Facility at Woodbridge, VA. Normal operational environments are at approximately 50 kV/m, free field, at 50 m on the centerline. The AESOP simulator is virtually identical to the TEMPS (Transportable EMP Simulator) in design and capability except that TEMPS is transportable.

aperture--Any opening in a shield that allows electromagnetic radiation to penetrate the shielded environment. Common examples of apertures are windows, doors, and vents.

bonding--The process whereby two or more conductors are fastened together to provide electrical continuity. The purpose of bonding is to fabricate shields, make grounding connections, and interconnect circuits.

central processing unit (CPU)--A unit of a computer that includes the circuits controlling the interpretation and execution of instructions. Synonymous with main frame.

checkpoint--A process whereby critical information is recorded on a backup or redundant storage medium for use in a rollback or restart operation in the event the primary information is lost or damaged.

checkpoint rollback (CPRB)--A fault-tolerance technique used to protect against the effects of upset. A process whereby (1) critical information is periodically and routinely recorded on a backup or redundant storage medium and (2) when an upset fault is detected, any lost or damaged information is restored from the checkpointed copy and a restart is performed.

cold backup--A circuit/peripheral/subsystem that is a functional replacement for an operating unit and is powered-down and possibly physically disconnected. (See also "hot backup," "warm backup.")

coverage--The probability of recovery, given that a fault occurs.

CPRB--See checkpoint rollback.

CPU--Central processing unit.

damage--The irreversible failure of an electrical component. Examples are (1) burnout of a transistor, diode, or integrated circuit, (2) degradation of a semiconductor's operating characteristics such that it will no longer function as intended, and (3) voltage breakdown of a capacitor or resistor.

DAS3--Decentralized Automated Service Support System.

degraded recovery--The return of the system to a fault-free state, but with a reduced computing capacity. This means that some hardware elements have been discarded without replacement, some programs or data have been lost, or some functions have taken longer than the allowed time.

detection (fault detection)--The first phase of a fault-tolerance process; the other phase is recovery. Detection in its most general use can take several forms, as follows: (1) Initial testing, which takes place before normal use and serves to identify faulty hardware elements containing imperfections introduced during the manufacturing or assembly process. (2) Concurrent (online) detection, which takes place simultaneously with normal operation of the system. (3) Scheduled (offline) detection, which takes place when normal operation is temporarily interrupted. (4) Redundancy testing, which serves to verify that the various forms of protective redundancy are themselves fault-free, and takes place either concurrently or at scheduled intervals.

determinate fault--A fault where the value of a logic variable assumes a constant value as a result of the fault.

distributed fault--Distributed (related multiple) faults are those that affect two or more variables, a module, or an entire system.

downtime--The time during which a system or system element is malfunctioning.

DSU--Direct Support Unit.

DS4--Direct Support Unit Standard Supply System.

EMC--Electromagnetic compatibility.

EMI--Electromagnetic interference.

EMP--Electromagnetic pulse, generated by detonation of a nuclear weapon.

fault--An abnormal condition of hardware, software, or data that may cause a deviation of the information-processing behavior from the expected and desired sequence. Fault includes damage and upset caused by EMP.

fault avoidance--An attribute whereby a system, subsystem, or circuit avoids a fault condition in spite of the presence of a disturbance (such as an electrical transient). Fault avoidance includes installation of devices to reduce a transient to an acceptable level, designing the electronics so that the system is insensitive to the transient, or both.

fault tolerance--An attribute whereby a system, subsystem, or circuit continues to operate in the expected manner in spite of a fault. Electrical circuitry, software, or operating procedures are specially designed or supplemented so that faults are detected and are either ignored or corrected. Fault-tolerance measures can be implemented as software, hardware, operating procedures, or as combinations of these.

full recovery--The return of the system, within allowed time limits, to the conditions that existed before the fault occurred. Both the hardware and software possess the same computing capacity as before. Failed hardware modules are replaced by spares. Damaged information (programs and data) is returned to a known good state that existed before the fault.

GFE--Government-furnished equipment.

grounding--A procedure for controlling the potential of electrical, electronic, and nonelectrical conductors within a shielded region with respect to each other and to the shields. Grounding of electrically operated equipment and structural metal is primarily for personnel protection and the prevention of fire and explosion. Grounding of small-signal electronic and radio circuits is primarily to protect components against damage or malfunction caused by uncontrolled potential differences (drift) between the circuit and other conductors such as the housings, cabinets, shields, or other circuits.

GSU--General Support Unit.

Hamming code--A data code which can be corrected automatically.

hardware--Physical equipment (as opposed to the computer program or method of use); for example, mechanical, magnetic, electrical, or electronic devices. Contrast with software.

hardware redundancy--Redundancy that involves the use of redundant components, circuits, or subsystems (including computer peripherals) to protect against faults. Redundancy can be provided, so that identical functions are performed for comparison to detect errors, or it may be provided as a means of backup if an active unit fails.

HDL--Harry Diamond Laboratories. The Army's lead laboratory for nuclear weapons effects research and testing.

HEMP--High-altitude electromagnetic pulse.

HEMP hardening--The process of incorporating design practices with the objective of providing survivability to an HEMP environment.

hot backup--A circuit/peripheral/subsystem that is a functional replacement for an operating unit and is powered-up and operating. (See also "warm backup," "cold backup.")

indeterminate fault--A fault where the value of a logic variable varies throughout the duration of the fault.

instruction retry--An automatic hardware or system software process whereby instruction results are checked and re-executed if an error is detected. Instruction retry can be an effective means for providing protection against transient (temporary) EMP upsets to instruction information or circuitry.

KVDT--Keyboard visual display terminal.

local fault--Local (single) faults are those that affect only single logic variables.

LSI--Large-scale integration.

MEP--Mobile electric power.

MERADCOM--Army Mobility Equipment Research and Development Command.

MSI--Medium-scale integration.

offline--Pertaining to equipment, devices, or storage media that are not under the control of the central processing unit. Contrast with online.

online--Pertaining to equipment, devices, or storage media that are under the control of the central processing unit. Contrast with offline.

penetrator--Any conductive medium that penetrates a shield boundary. Common penetrators include pipes, power lines, ground conductors, antennas, telephone lines, and other signal conductors.

permanent fault--A fault caused by irreversible failures of components.

plausibility checks--Usually software or possibly human checks which verify that information being processed or which is the result of computations falls within realistic bounds. Plausibility checks are useful for detection of errors caused by upset.

process redundancy--Redundancy that involves the multiple execution of a process and comparison of the results. Process redundancy is useful for fault detection.

real-time--(1) Pertaining to the actual time during which a physical process transpires. (2) Pertaining to the performance of a computation during the actual time that the related physical process transpires in order that results of the computation can be used in guiding the physical process. (3) Pertaining to an application in which response to input is fast enough to affect subsequent input, such as in a process control system.

recovery--The second phase of a fault-tolerance process; the first phase is fault detection. Recovery is the procedure that is initiated when a fault has been detected in order to return the system to normal operation. Recovery may return the system to the same state as before the fault (see full recovery), to a degraded mode (see degraded recovery), or to a safe shutdown (see safe shutdown).

RFI--Radio frequency interference.

rollback--A process whereby, upon the detection of a fault, critical information is restored from a previous checkpoint and the process or system is restarted at the point of that checkpoint.

safe shutdown--The limiting case of degraded recovery. It is carried out when the remaining computing capacity (if any) is below the minimum acceptable threshold. The goals of shutdown are to avoid damage to remaining stored information and good system elements, to cease interaction with other systems or human users in a specified orderly fashion, and to deliver shutdown messages and diagnostic information.

shielding--Separation of electromagnetic environments by barriers of high-conductivity materials, usually metals, which may be ferromagnetic. The objective of shielding is to make the electromagnetic environment in one region relatively independent of the environment in an adjacent region (on the other side of the shield).

software--In general: A set of programs, procedures, and possibly associated documentation concerned with the operation of a data processing system; for example, compilers, library routines, manuals, circuit diagrams. Software as used in this document does not include procedures and documentation. Contrast with hardware.

SOP--Standard operating procedures.

TACMIS PMO--Tactical Management Information Systems Project Management Office.

TARCOM--Army Tank Automotive Materiel Readiness Command.

terminal protection device (TPD)--A protection device applied to a penetrator at the point where it enters a shielded environment in order to reduce the energy coupled into system electrical circuits via that penetrator. TPD's include surge-suppression devices and filters.

throughput--The total volume of work performed by a computer system over a given period of time.

time-out error--Time-out is the time allotted for certain operations to occur; for example, response to polling or addressing, or performance of input/output. A time-out error occurs if the task takes more time than has been allotted.

timer--A hardware or software mechanism which monitors on-going tasks to assure that the normal time required for the task is not exceeded. Timers are useful for fault detection.

TPD--See terminal protection device.

transient fault--A fault of limited duration caused either by temporary malfunctions of components or by external interference.

trap--A conditional jump to a known location, automatically activated by hardware, with the location from which the jump occurred recorded. Traps are useful for fault detection.

TSARCOM--Army Troop Support and Aviation Materiel Readiness Command.

upset--The unwanted action of a system, subsystem, or component. Examples are (1) altering of a flip-flop state, (2) altering of one or more bits in a memory word or register, (3) communication errors, and (4) misread, miswritten, or overwritten areas of storage or memory.

warm backup--A circuit/peripheral/subsystem that is a functional replacement for an operating unit and is powered-up but not in use. (See also "hot backup," "cold backup.")

DISTRIBUTION

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

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

COMMANDER
US ARMY MATERIEL DEVELOPMENT &
READINESS COMMAND
ATTN DRXAM-TL, HQ TECH LIBRARY
5001 EISENHOWER AVENUE
ALEXANDRIA, VA 22333

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

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

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

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

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

COMMANDER
US ARMY COMPUTER SYSTEMS COMMAND
TACMIS PMO
ATTN ACSC-TP, LTC ERNEST K. SCOTT
(15 COPIES)
FORT BELVOIR, VA 22060

HQ DEPT OF THE ARMY
ATTN DAMA-CSC-CC, LTC CLUNE
ATTN DAAC-PE, LTC STUART
WASHINGTON, DC 20310

PRODUCT MANAGER
AUTOMATIC TEST SUPPORT SYSTEMS
ATTN DRCPM-ATSS,
LTC R. AMMERMAN, JR.
ATTN DRCPM-ATSS, N. KARALEKAS
ATTN DRCPM-ATSS, A. CROCE
FORT MONMOUTH, NJ 07703

COMMANDER
US ARMY CORADCOM
ATTN DRDCO-PE-T (5 COPIES)
FORT MONMOUTH, NJ 07703

COMMANDER
US ARMY TARCOM
ATTN DRDTA-WS, MCKINLEY
WARREN, MI 48090

GE-MATSCO
ATTN HARRY TUCCI (5 COPIES)
VALLEY FORGE SPACE CENTER
P.O. BOX 8555
PHILADELPHIA, PA 19101

DIRECTOR
DEFENSE NUCLEAR AGENCY
ATTN VLIS, MAJ E. BURKETT
WASHINGTON, DC 20305

US ARMY ELECTRONICS RESEARCH
& DEVELOPMENT COMMAND
ATTN WISEMAN, R. S., DR., DRDEL-CT
ATTN KELLEY, C. S., DRDEL-AP-CCM

PRECEDING PAGE BLANK

DISTRIBUTION (Cont'd)

HARRY DIAMOND LABORATORIES
ATTN 00100, COMMANDER/TECH DIR/TSO
ATTN RECORD COPY, 94100
ATTN HDL LIBRARY, 41000 (3 COPIES)
ATTN HDL LIBRARY, 41000 (WOODBRIDGE)
ATTN TECHNICAL REPORTS BRANCH, 41300
ATTN CHAIRMAN, EDITORIAL COMMITTEE
ATTN CHIEF, DIV 10000
ATTN CHIEF, DIV 20000
ATTN CHIEF, DIV 30000
ATTN CHIEF, DIV 40000
ATTN CHIEF, 20240
ATTN CHIEF, LAB 21000
ATTN CHIEF, LAB 22000
ATTN CHIEF, BR 21100
ATTN CHIEF, BR 21200
ATTN CHIEF, BR 21300
ATTN CHIEF, BR 21400
ATTN CHIEF, BR 21500
ATTN CHIEF, BR 22100
ATTN CHIEF, BR 22300
ATTN CHIEF, BR 22800
ATTN CHIEF, BR 22900
ATTN AGEE, F., BR 21100
ATTN BASSETT, D., BR 21100
ATTN CAMPI, M., BR 21100
ATTN CHASE, R., BR 21100
ATTN CLARK, S., BR 21100
ATTN FAZI, C., BR 21100
ATTN GARVER, R., BR 21100
ATTN GAUL, E., BR 21100
ATTN JOHNSON, A., BR 21100
ATTN MILETTA, J., BR 21100
ATTN PENAR, J., BR 21100
ATTN ROFFMAN, G., BR 21100
ATTN ROSE, T., BR 21100 (30 COPIES)
ATTN SANDERS, S., BR 21100
ATTN SCHUMAN, W., BR 21100
ATTN WARD, A., BR 21100
ATTN WASHINGTON, J., BR 21100
ATTN LEPOER, K., BR 22100
ATTN WIMENITZ, F. N., 20240
ATTN SCOTT, W. J., 21500
ATTN DANDO, J., 21400