ELECTROMAGNETIC PULSE (EMP) AND TEMPEST PROTECTION FOR FACILITIES

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CHAPTER 8

EMP AND TEMPEST RISKS

8-1 Outline. This chapter is organized as follows:

8-2. Introduction. System design greatly influences the impact a HEMP event has on a facility. Thorough knowledge of the various modes of HEMP coupling to structures combined with system sensitivity information and TEMPEST risks can give designers better insight into HEMP hardening and TEMPEST protection requirements for critical facilities.

8-3. EMP environment--overview.

a. General.

(1) Classification of EMP. EMP can exist in many forms. Typically, EMP is classified in terms of the height of burst (HOB) of the detonation and its relative relationship with respect to the target or observer. For this pamphlet, only the high-altitude detonation is considered since this environment can be considered for all critical facilities. Additional scenario-dependent environments would apply to targeted facilities or those located near targets.

(2) High-altitude burst. A high-altitude burst occurs above approximately 30 kilometers and differs from surface and air bursts in that other associated nuclear effects do not occur on the ground. EMP is the major effect.

(3) Generation of HEMP. Figure 8-1 depicts the generation of HEMP. The gamma rays produced by the burst travel radially from the burst in a spherical shell that expands at the speed of light. Below 30 kilometers, the atmosphere is dense enough to cause gamma rays to be absorbed by Compton scattering. This effect results when gamma rays from the nuclear burst collide with air molecules. Absorption is nearly complete by the time the gamma rays reach an altitude of 20 kilometers. Thus, the source region for a high-altitude burst is located between 20 and 30 kilometers above the Earth's surface. This region is shaped like a pancake and its lateral extent is limited only by the curvature of the Earth.

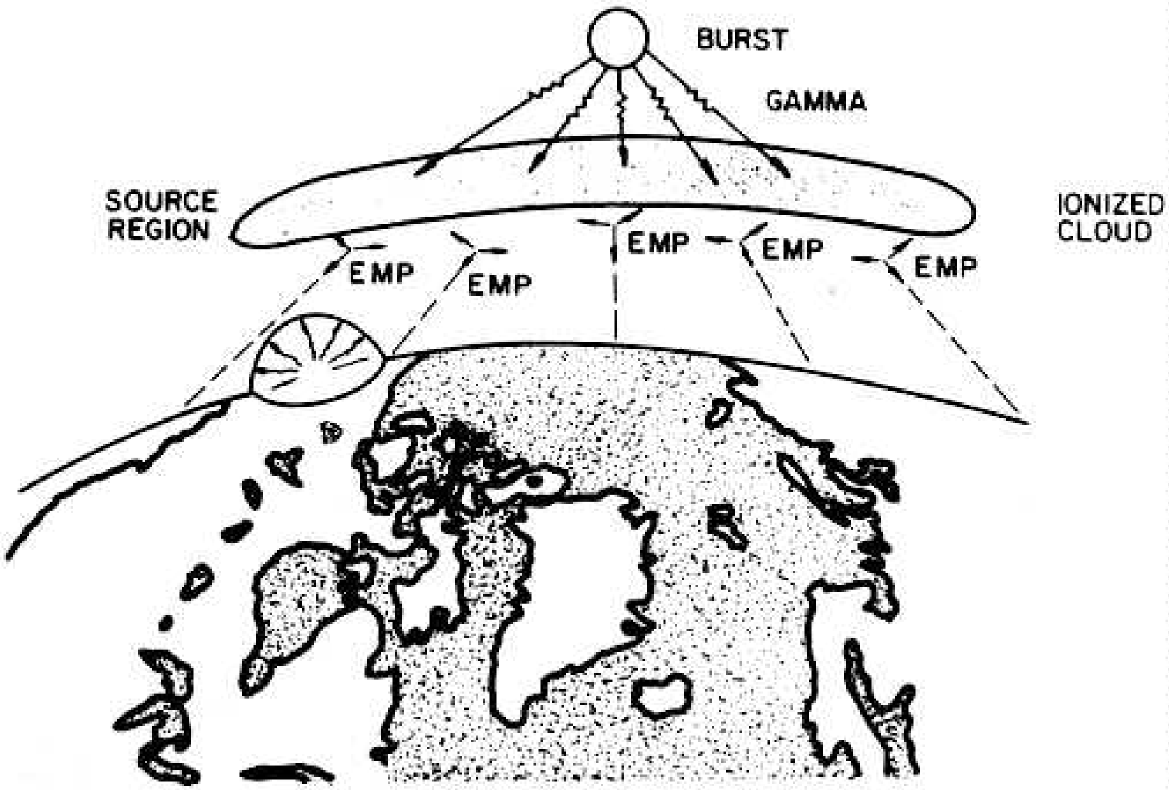

Figure 8-1. Near-surface and exoatmospheric blasts.

(4) Compton electrons. At the altitude of the source region, the Compton electrons travel about 100 meters before they are absorbed. While traveling this distance, the electrons are strongly deflected by the Earth's geomagnetic field, making them turn with a radius of about 100 meters. Thus, the Compton current has large components in nonradial directions from the burst, i.e., transverse to the direction of the gamma-ray propagation, which are effective in generating radiated fields. The transverse Compton current is the primary source of high-altitude radiated EMP. HEMP consists of radiated electric and magnetic fields that begin almost at once and persist for more than 100 seconds. Typically, for design-related considerations, only the fields produced in the first microsecond (early time) after the burst are considered. However, as the impacts of intermediate and late-time effects become better defined, additional consideration may be required.

(5) Relationships. In general, characteristics such as the spatial extent, time waveform, and peak amplitude of HEMP depend on the HOB, weapon yield, and observer's location with respect to the burst. The following paragraphs show the characteristics of a nonclassified but representative

HEMP.

b. Electric field. The time waveform of a HEMP electric field, E(t), in free space can be approximated by the analytic expression--

$$E(t) = \frac{kE_{pk}ea(t-t_s)}{l+e^{(a+b)(t-ts)}} (kV/m)$$

(eq 8-1)

where the coefficients are given by--

E_{pk} = 50 kVtm, the peak electric field (kV/meter)

k = 1.2, a normalization constant

a = 5×10^8 sec^{-1}, the exponential rise rate (sec^{-1})

b = 2.3×10^7 sec^{-1}, the exponential decay rate (sec^{-1})

$T_s = 10^{-8}$ sec, the time shift parameter (sec)

t = the time of interest (sec).

Figure 8-2 is a graphic representation of the HEMP waveform.

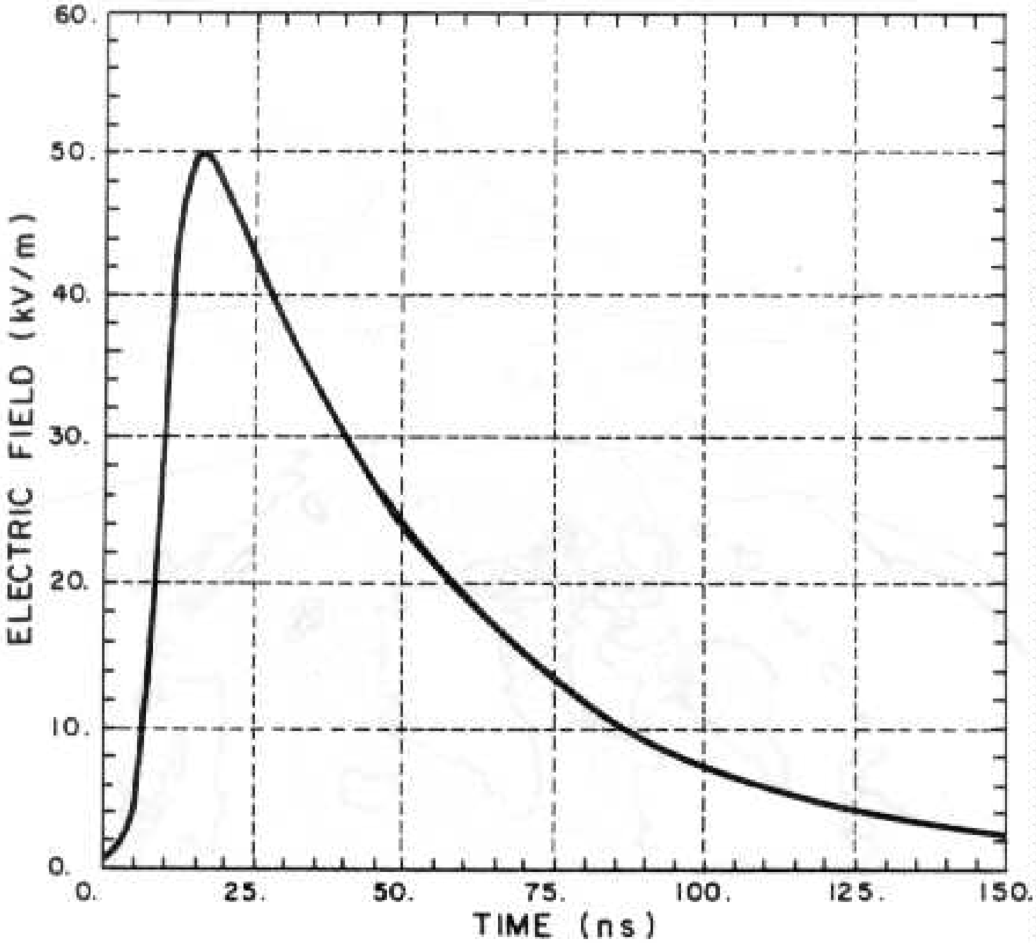

Figure 8-2. Time waveform for the free-field HEMP electric field.

c. Magnetic field. The associated magnetic component of the radiated HEMP field can be obtained by dividing the electric field in volts per meter by 377 ohms. This gives the magnetic field in amps per meter with a peak value of about 135 amps per meter. It should be noted, however, that the values shown in figure 8-2 apply only to the free-field environment and not to the behavior of fields near conducting surfaces such as the surface of the Earth. Near such a conductor, the electric field will be much smaller because it is shorted out, whereas the magnetic field will be about twice its value in free space, or almost 270 amps per meter.

d. Spatial extent.

(1) Geographical coverage. The geographical coverage of HEMP over the Earth's surface is determined entirely by the HOB. The maximum ground range (tangent radius) depends on the tangent to the Earth from the burst point and is the arc length between this tangent and the point on the Earth's surface directly beneath the burst surface zero. To approximate this distance, the

following calculation for tangent radius RT (in kilometers) can be made:

$$R_T = R_E \cos^{-1}\left(\frac{R_E}{R_E + HOB}\right)$$

(eq 8-2)

where R_E = 6370 kilometers (the approximate radius of the Earth) and HOB is the burst height in kilometers.

(2) Surface area calculation. The total surface area A_T in square kilometers covered by HEMP can be calculated as follows:

$$A_T = \frac{2(pi)R_E^2\ HOB}{R_E + HOB}$$

(eq 8-3)

Figure 8-3 applies this information to the United States, showing ground coverage for bursts of 50 and 120 miles over the central portion.

Figure 8-3. HEMP ground coverage for bursts of various heights above the United States. (Source: ref 8-14)

e. HEMP peak fields at the Earth's surface.

(1) Orientation of Earth's geomagnetic field. Since the motion of the compton electrons depends on the orientation of the Earth's geomagnetic field, the incident HEMP fields vary significantly in peak amplitude, rise time, and duration over the large area affected by the HEMP. The maximum peak electric field E_{max} occurs just south of ground zero and can be as high as 50 kilovolts per meter, depending on the HOB and the weapon yield. The peak field E_{pk} observed at any other location is some fraction of E_{max}.

(2) Geometric factors. In addition to the orientation and dip of the geomagnetic field, geometric factors based on the observer's position with respect to the burst also cause spatial variations of the HEMP field strength. In the figure, the null area slightly north of the burst point is produced by the geomagnetic dip over the CONUS; Compton electrons created in the same direction as the Earth's geomagnetic field do not turn and no radiated fields are created. The maximum peak fields are found at a distance equal to about

twice the HOB south of surface zero.

8-4. Comparison of HEMP and lightning. HEMP-induced surge currents on overhead transmission lines are similar to, but not exactly the same as, lightning-induced surges. Table 8-1 compares worst-case surges. From the numerical values, it could be inferred that lightning is a more serious threat. The values for lightning, however, represent the 99th percentile of all measurements on standard lightning discharges, and thus may not be representative of the strokes that occur near a given facility. In contrast, the HEMP pulse is not a localized phenomenon, but illuminates a very wide area. As a result, any hardened facility would see a HEMP-induced current if there were a war, while it might never be exposed to the maximum lightning current. In addition, there are significant differences in pulse rate and frequency content. For this reason, it cannot be assumed that standard lightning protection is an adequate substitute for HEMP protection.

8-5. TEMPEST risks.

a. TEMPEST objectives.

(1) Communication security (COMSEC). Communication security (COMSEC) is the term used to denote steps taken to prevent disclosure of national security information to unauthorized recipients during the communication process. NTISSI 7000 and AR 530-4 define minimum measures that must be taken to protect CONUS facilities (refs 8-1 and 8-2). The information to be guarded includes plain text of classified messages, as well as cryptographic technology and materials. Cryptographic information is especially sensitive, not as an end in itself, but because it is used to protect other classified data. If the integrity of an encryption system is breached at any point, all classified information protected by that coding may be compromised.

(2) Parts of COMSEC. COMSEC consists of four main parts: physical security--all physical measures to safeguard materials from unauthorized access; emissions security-control of emanations from equipments processing classified data; transmission security--protection of transmissions from traffic analysis, imitative deception, and disruption; and cryptographic security--the use of technically sound cryptosystems. Only the emissions security discipline or TEMPEST is specifically addressed in this manual.

(3) Details of TEMPEST issues. Because the details of many TEMPEST issues are classified and controlled under strict conditions of need-to-know, the following discussions must be somewhat general. Nevertheless, it provides the reader with a needed aPpreciation of TEMPEST fundamentals.

(4) Theory of electromagnetic signal emanation. Any electrical/electronic circuit that carries a time-varying current will emanate electromagnetic signals with the strength of the emission proportional to the current amplitude and its time rate of change. These signals propagate outward from the source as free space waves and as guided waves along conductors connected to or close to the radiator. If time variations of the

source currents are related in any way to the information content of the signals (which will almost certainly be the case on a data line~, then the emanation will also bear some relationship to the data. It may, therefore, be possible to reconstruct the original intelligence by analysis of these unintentional emissions.

(5) Aim of TEMPEST discipline. Finally, if the source information is classified, interception and analysis of the emanations by unauthorized personnel will compromise national security. The aim of the TEMPEST discipline is to control stray emissions in a manner that prevents such disclosures.

b. Equipment emission characteristics.

(1) RED and BLACK terminology. Before addressing the emission characteristics issue, the RED and BLACK terminology will first be introduced. A RED equipment or circuit is one that handles plain text information with national security value. Equipment processing signals that are unclassified, either because of content of the text or because the intelligence is obscured by encryption, is denoted in BLACK.

(2) Strength and nature of emanations. The unintentional emission characteristics of RED systems and equipments are categorized according to strength and nature of their emanations. The reason for the strength element is clear: high-level signals can be intercepted at magnitudes that permit analysis with greater physical separations between the source and the eavesdropper. The second factor relates to the correlation between waveform of the emitted signal and the information to be protected.

(3) Classes of equipment. For purposes of facility engineering and construction within the limitations of this manual, it is only necessary to define two classes:

(a) Equipments that are TEMPEST-approved according to the criteria established in the current edition of NACSIM 5100 (ref 8-3).

(b) All equipments that have not been TEMPEST-tested or are nonapproved.

(4) Project development brochure. Information regarding the category of RED equipment to be protected should be presented in the project development brochure prepared by the user of the facility.

c. Detection capabilities.

(1) Electromagnetic surveillance concerns. Concerns about electromagnetic surveillance have been intensified by advances in state-of-the-art equipment design and signal processing techniques. While a few technologies such as fiber optics and multiplexing have made interception and analysis more difficult, the overall effect has been to open new opportunities

for eavesdroppers. Projections into the immediate future indicate that this trend will continue.

(2) Worst-case evaluation. The only safe approach is a reasonable worst-case evaluation. It must be assumed that the opposition has the proper equipment to monitor all signals of significant amplitude in areas where access is uncontrolled.

d. TEMPEST isolation requirements.

(1) Isolation approaches. Encryption is the method used to guard against disclosure of classified information when long-distance telecommunications are monitored. However, it does not prevent possible compromise through interceptions and analyses of unintentional emanations from RED equipments.

(a) Many approaches are available to equipment and facility designers to avoid disclosures through potentially compromising emanations. All of these techniques reduce the stray signal strength at locations where access is uncontrolled, so that the intelligence content is lost in the background electrical noise. AR 530-4 should be consulted to determine the level of protection required.

(b) Examples of preventive measures include the following:

- Physical separation--excluding unauthorized individuals from areas near the source where the emanations are larger in amplitude than the ambient noise.

- Electromagnetic separation--the use of shielding, filtering, and other methods of EM isolation to attenuate the unintentional emissions.

- Signal level minimization--design and operation of circuits at lowest feasible power levels to minimize the strength of unintentional emissions.

(c) These methods can be employed in an infinite variety of combinations to achieve the desired goals.

(2) Recommended TEMPEST isolation concept. NTISSI 7000 and AR 530-4 analysis is the first step in determining needed TEMPEST countermeasures. Shielding for TEMPEST is not necessarily required; however, for facilities having high-confidence HEMP survivability specifications and being hardened in accordance with recommendations of this manual, it is technically prudent and highly cost-effective to include TEMPEST shielding and penetration protection in a common subsystem. The suggested TEMPEST isolation concept takes advantage of this principle.

(a) The first requirement, a physical security measure, is the establishment of a controlled space (CS) containing the equipment to be

TEMPEST-protected and within which access is not available to those not authorized to receive the information being processed at the site.

(b) NACSEM 5204 defines the detailed procedures to compute shielding effectiveness requirements for specific TEMPEST applications (ref 8-4). Parameters of the problem include measured emission characteristics of the equipments and distance to the perimeter of the controlled space. The calculation determines the attenuation needed to reduce emanation levels below detectable limits in the ambient noise environment. If reasonable worst-case assumptions are made regarding the variables, however, then 50 decibels (nominal) attenuation is adequate for an installation within CONUS. This requirement can be met by a shield and penetration treatments that conform to Specification NSA No. 73-2A.

(c) NSA 73-2A is an appendix in NACSEM 5204. The document also contains Specifications NSA No. 65-5 and 65-6 for TEMPEST applications where greater shielding effectiveness requirements exist. DIAM 50-3A should be consulted for SCIF shielding information (ref 8-5).

(3) TEMPEST design criteria. Since electromagnetic performance requirements of a 50-decibel (nominal) TEMPEST design are quite consistent with performance necessary for HEMP considerations and only a few additional features are prescribed for the shielding and penetration protection subsystem, the reasonable worst-case TEMPEST assumptions have been incorporated into the recommended HEMP/TEMPEST approach. The following paragraphs summarize the TEMPEST-unique requirements for facility design.

(a) Shielding effectiveness. Minimum attenuation levels of the shielded enclosure, when measured in accordance with NSA 73-2A, are as shown in figure 8-4. This curve contains a slight increase in the requirements at frequencies above 500 megahertz compared with values prescribed in NSA 73-2A. The upper frequency of the shielding effectiveness and filter insertion loss frequency have also been extended as high as 10 gigahertz. The site-specific requirements should be determined by consulting with the using agency.

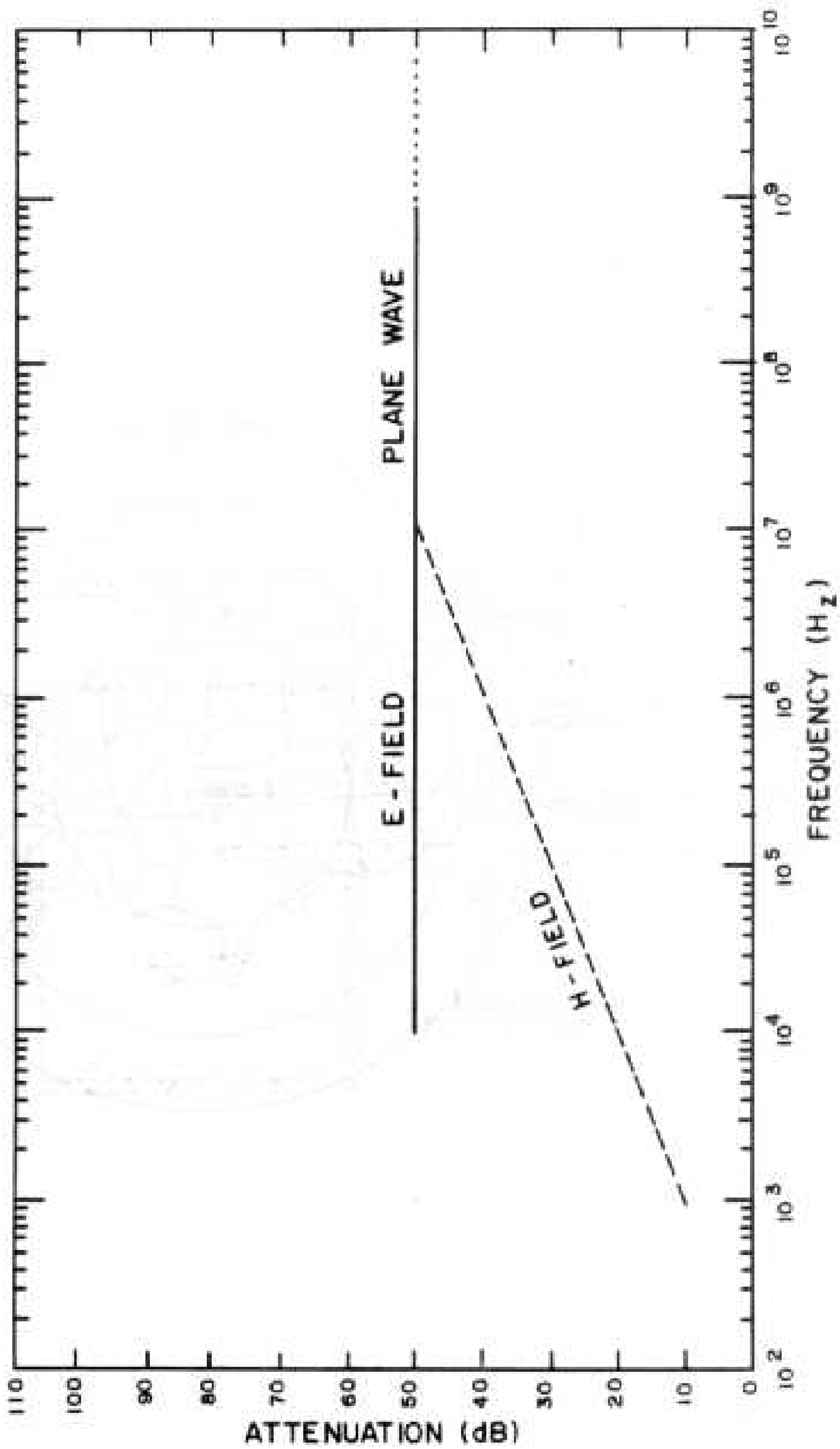

Figure 8-4. Reasonable worst-case TEMPEST shielding attenuation requirement.

(b) Shield doors. TEMPEST shield design includes a shielded vestibule entrance arrangement with two doors oriented at 90 degrees to each other. The purpose of double doors is the same as that cited for HEMP--to preserve the shielding effectiveness during actual entries and exits. Effectiveness requirements for the doors are the same as those for the main shield.

(c) Piping and ventilation penetration. Mechanical penetrations, piping, and air ducts are to be bonded to the shield at the point of penetration. The design must be configured as a waveguide-beyond-cutoff to attenuate all frequencies within the specified band, as shown in figure 8-5.

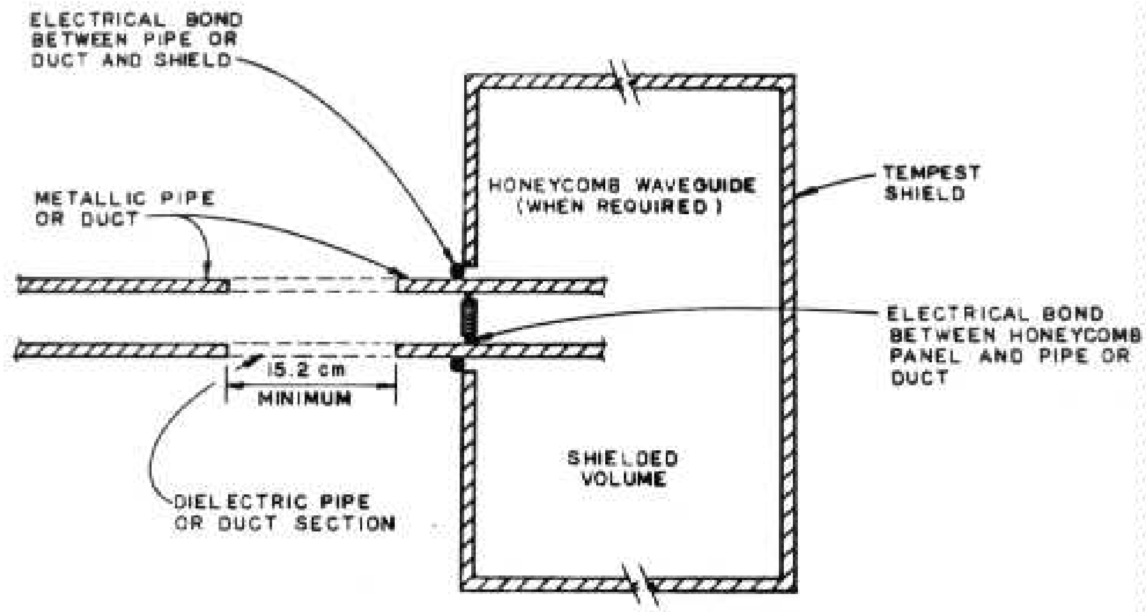

Figure 8-5. Fifty-decibel (nominal) TEMPEST pipe or air duct penetration design.

(d) Electrical penetration. The specification requires that a filter providing at least 50 decibels of insertion loss from 14 kilohertz to the upper design protection frequency, typically 1 to 10-gigahertz upper frequency when measured in accordance with procedures of MIL-STD-220A, be installed on each power, telephone, and signal line that penetrates the enclosure shield wall (ref 8-6). (Note: Other forms of isolation, such as optical or pneumatic decouplers, which accomplish the same purpose, may be used and special performance specifications for filters on conductors with operating signals in the 14 kilohertz to 1-10 gigahertz band may be established, subject to the approval of the using agency.)

e. Installation within the shielded volume.

(1) Precluding unintentional coupling. It is virtually certain that the volume enclosed by the TEMPEST shield will contain some BLACK equipment and wiring, as well as RED circuits that handle national security information. Therefore, the facility design and hardware/wiring layouts must preclude unintentional coupling of RED emanations into BLACK conductors. These measures are above and beyond the shielding and penetration protection

subsystem features and are necessary whether or not a shield is provided.

(2) Sources of additional information. The guidelines and requirements for RED/BLACK isolation are published in NACSIM 5203 (ref 8-7) and MIL-HDBK-232A (ref 8-8). Since some details of the specified practices are classified, this discussion must be considered incomplete, and the designer must also consult NACSIM 5203 and MIL-HDBK-232A to comply with the minimum requirements.

(3) Limited exclusion area. The room or area within which RED equipment is located and to which controls are applied for protection of national security information is known as a limited exclusion area (LEA). The TEMPEST shield may enclose part or all of the LEA and might also envelope other sPaces.

(4) Spacing of equipment. RED equipment must be physically separated from the facility walls and ceiling, from BLACK equipment and wiring, and from utility conductors such as ventilation ducts and piping. Minimum required spacings depend on whether the RED equipment is low-level signaling, TEMPEST-approved hardware or not, and on the nature of possible propagation paths between the BLACK element and an area of uncontrolled access.

(5) Penetrations. Physical separation practices, as well as special shielding and distribution (for example, using conduits, ducts, and trays) instructions, also apply between RED and BLACK wiring in the LEA. Specific guidelines are presented in NACSIM 5203 for signal lines, telephone/communication cables, power feeders, ground wires and other utility (air-conditioning control and status, fire alarm) electrical conductors. Markings with paint or tape are prescribed to distinguish RED wiring runs from BLACK cables, and RED conduits must be accessible for inspection.

(6) Separating RED and BLACK. Also, depending on characteristics of the RED equipment, separate filter-isolated RED and BLACK power distribution subsystems or individual equipment power filters may be required. Further, it may be necessary to provide separate and distinctively identified RED and BLACK convenience outlets.

(7) Telephones and intercoms. Administrative telephone and facility intercommunication subsystems require particular attention. The most effective protection is to eliminate or, at least, minimize the number of instruments in the LEA. If exclusion is not practical, separation, shielding, and filter isolation devices and positive disconnect capabilities are to be provided as prescribed in NACSIM 5203.

f. Related TEMPEST documents.

(1) National Security Agency documents. The reader desiring additional background material concerning TEMPEST and needing specific implementation information is directed to the series of TEMPEST source documents published by the National Security Agency (NSA). Supplementary use of these references during facility design and construction phases is imperative because

classification considerations limit the information incorporated in this manual to generalized discussions. Only the shielding and penetration protection requirements are included in this manual.

(2) National COMSEC Information Memorandums. NACSIM 5000 provides an overall introduction to the TEMPEST discipline (ref 8-9). NACSIM 5203 and NACSEM 5204 are essential to the project for defining installation requirements within the protected volume and the shielded enclosure requirements, respectively (refs 8-7 and 8-4). Other documents to which the reader may wish to refer include: NACSI 5004 (ref 8-1), NACSI 5005 (ref 8-10), NACSIM 5100A (ref 8-3), NACSEM 5109 (ref 8-11), NACSEM 5110 (ref 8-12), and NACSEM 5201 (ref 8-13). The military departments (MILDEPs) also publish TEMPEST regulations and guidance; access to these documents can be obtained through the appropriate MILDEP communication security agency.

8-6. Cited references.

8-1. National Telecommunications and Information System Security Instruction (NTISSI) 7000, 17 October 1988.

8-2. Army Regulation (AR) 530-4, (U) Control of Compromising Emanations (Headquarters, Department of the Army [HQDA]) (C).

8-3. National COMSEC Information Memorandum (NACSIM) 5100A, (U) Compromising Emanations Laboratory Test Requirements, Electromagnetics (NSA) (C).

8-4. National COMSEC/Emergency Security (EMSEC) Information Memorandum (NACSEM) 5204, (U) Shielded Enclosures (NSA, January 1979) (C).

8-5. Defense Intelligence Agency Memorandum (DIAM) 50-3A, Physical Security Standards for Sensitive Compartmented Information

Facilities (Defense Intelligence Agency, 2 October 1984).

8-6. Military Standard (MIL-STD) 220A, Method of Insertion-Loss Measurement (Department of Defense [DOD], 15 December 1959).

8-7. NACSIM 5203, (U) Guidelines for Facility Design and RED/BLACK Installation (NSA, 30 June 1982) (C).

8-8. Military Handbook (MIL-HDBK) 232A, (U) RED/BLACK Engineering Guidelines (DOD, 25 April 1980) (C).

8-9. NACSIM 5000, (U) TEMPEST Fundamentals (NSA, 1 February 1982) (C).

8-10. National COMSEC Instruction (NACSI) 5005, (U) TEMPEST Countermeasures for Facilities Outside the United States (NSA, January 1984) (S).

8-11. NACSEM 5109, (U) TEMPEST Testing Fundamentals (NSA) (C).

8-12. NACSEM 5110, (U) Facility Evaluation Criteria--TEMPEST (NSA, July 1973) (S).

8-13. NACSEM 5201, (U) TEMPEST Guidelines for Equipment/System Design (NSA, September 1978) (C).

8-14. DNA EMP Course Study Guide, draft prepared for Defense Nuclear Agency (The BDM Corporation, April 1983).

Table 8-1. Comparison of HEMP with lightning-induced stresses on long overhead power lines.

HEMP phenomenon	V_{max} (MV)	I_{max} (kA)	dV/dt (kV/ns)	dI/dt (A/ns)	S/Idt2 (Coulombs)	S/I dt (A^2-sec)	S/IVdt (Joules)
HEMP on long overhead power lines	6	14	40	100	10^{-2}	150	$6x10^4$
HEMP on short overhead power lines	1	2.5	40	100	$2x10^{-3}$	5	$2x10^3$
HEMP on buried power lines	1	2.5	8	20	--	--	--
Direct lightning strokes (Max)	100	100	0.8 to 8	2 to 100	40	$3.1xl0^6$	$1.2x10^8$
(Typical)	10	25					
Indirect lightning strokes (Max)	6	15	--	--	4.5	$1.8x10^4$	$7x10^6$

Voltage computations assume a nominal power line surge impedance of 400 ohms. Lightning discharge estimates do not consider so-called "positive superbolts" which are anomalies, but are roughly l0 times more severe than normal lightning bolts.

[End Chapter 8]