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EMP Protection Validation Testing Approaches

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EMP Hardness Validation Testing Approach[1]

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Introduction

As a rule, system developers would rather validate their systems' hardness by analysis with, perhaps, some limited supporting subsystem testing. However, the overwhelming evidence points to the need for fully integrated and operational system testing. This need is particularly acute for the nuclear electromagnetic pulse (EMP).

The combined U.S. EMP system test experience indicates that, with very few exceptions, the location, nature and seriousness of system malfunctions observed during full-scale system tests were not predicted during pre-test analysis. Prudence dictates that validation of HEMP hardness must be firmly based on test data. Indeed, testing should occur on full operational systems or the highest practical level of system integration.

Subsystem testing poses problems in that isolated box behavior can be quite different from the same box's behavior when installed in an integrated, operating system. In this regard, the EMP experience mirrors that of the electronic warfare community.[2] Experienced analysts admit that electromagnetic effects depend on fine, even trivial details of system construction and circuitry which are difficult to model. Many details affecting system EMP response such as parasitic cable capacitance/inductance and high voltage breakdown potentials/locations are unknown even by the system designers because they do not influence normal system operation.

While analysis has an important supporting role in connection with test and evaluation programs, experience shows that purely analytical predictions of system effects are not reliable now and for the foreseeable future. To enable meaningful tests (and supporting analysis), it is important that systems be hardened using simple, controlled electromagnetic shielding topologies. This hardening approach combines two distinct features:

1) Metal enclosures to occlude free electromagnetic fields and serve as a ground path for diverted electrical transients, and
2) Enclosure penetration treatments to divert aperture and penetrating wire energy to ground.

Experience shows that testability and life cycle maintainability benefits more than compensate for higher initial costs associated with a good shielding design. In the absence of shields, the amount of hardness provided per unit of investment cannot be determined. Furthermore, without shields it is difficult to determine if EMP hardness has

[1] Originally published in the Nuclear Survivability Newsletter, DoD Nuclear Information Analysis Center, February 1991
[2] Aviation Week and Space Technology, 11 September, 1989, p82.

been compromised by construction and maintenance practices. MIL-STD-188-125 specifies such a hardening approach for fixed ground based C3I facilities. This approach, referred to as the "low risk" approach, is conceptually illustrated in figure 1.

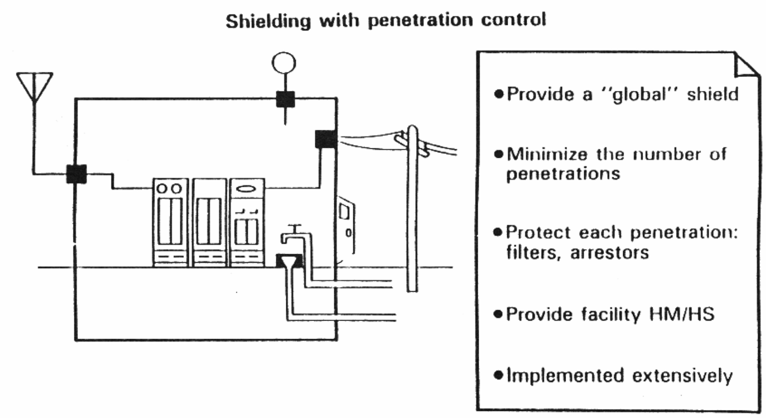

Figure 1. Low Risk Hardening-Shielding with Penetration Control

EMP Test Methods.
Two predominant test methods have evolved within the EMP community:
1. Threat-level field illumination (figure 2), and
2. Low level continuous wave (CW) illumination combined with threat-level pulsed current injection (PCI) on penetrating conductors (figure 3).

The choice of test type depends mainly on the size and mobility of the system to be tested. Threat-level field illumination is the preferred approach for mobile systems unattached to long line networks (viz. aircraft, ships, transportable C3I vans). Because of the need for portable test equipment, CW-PCI is the preferred approach for fixed ground based facilities.

Threat-Level Field Illumination Testing.
Threat-level field illumination (figure 2) gives the most direct and reliable indication of EMP survivability. This test type simultaneously checks the effectiveness of the system's shielding and penetration treatments. Threat-level field illumination testing is used most extensively for aircraft and ground mobile systems. The largest complement of threat-level field illuminators is located at the Air Force Research Laboratory in Albuquerque, NM. The Navy maintains an aircraft test facility at the Naval Air Test Center.

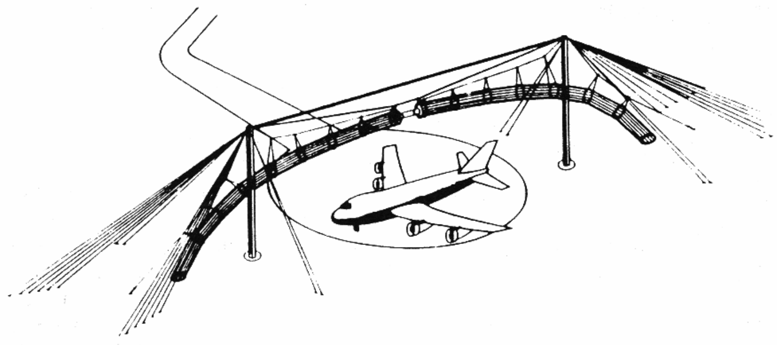

Figure 2. Threat Level Field Illumination

Improvements in large outdoor capabilities are required to fully replicate the DoD's EMP standard (DoD-STD-2169B). Of the U.S.'s full scale simulators, DTRA's ARES presently provides the most satisfactory replication of the criterion. However, the ARES' vertical polarization and lack of runway access limit its versatility as a general purpose simulator. Fidelity upgrades to other simulators have been proposed but it is probably more cost effective to build new designs expressly developed to simulate the criterion. The first such design, DTRA'S indoor FEMPS facility, produces criterion-like fields over shelter-sized objects. The case is building for deployment of a full scale outdoor criterion simulator. NEPA concerns make it prudent to locate new outdoor facilities at remote sites.

Continuous Wave / Pulsed Current Injection Testing.

The CW/PCI hardness test approach (figure 3) is valid only for systems which enclose mission critical electronics in a tight, well-defined electromagnetic barrier. As the name implies, testing is a two step process. First, the shield is illuminated by low level CW fields to check for leaks. Next, each conducting penetration is injected ("stressed") with threat-level current pulses to ensure that protection, consisting of filter and electrical surge arrestor (ESA) combinations, limit internal transients to specified maximum amplitudes, derivatives, and durations. Table I summarizes the injection waveforms and maximum admissible transients as stipulated in MIL-STD-188-125 for power line penetrations.

	Residual Internal Stress Limits			Pulsed Current Injection Requirements			
Class of Electrical POE	Type of Measurement	Peak Response Current (A)	Peak Rate of Rise (A/s)	Type of Injection	Peak Injected Current (A)	Risetime (s)	FWHM (s)
Commercial Power Lines (Intersite)							
Short Pulse	Bulk current	10	1×10^{6}	Common mode	8000	$\leq 1\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Short Pulse	Wire current	10	1×10^{6}	Wire-to-ground	4000	$\leq 1\times10^{-8}$	5×10^{-7}–5.5×10^{-7}
Intermediate Pulse	No damage or performance degradation			Common mode	500	$\leq 1\times10^{-6}$	$\leq 5\times10^{-3}$
Intermediate Pulse	No damage or performance degradation			Wire-to-ground	500	$\leq 1\times10^{-6}$	$\leq 5\times10^{-3}$
Long Pulse	No damage or performance degradation			Common mode	200	≤ 0.5	≤ 100
Long Pulse	No damage or performance degradation			Wire-to-ground	200	≤ 0.5	≥ 100

Table 1. Residual Internal Stress Limits and Injected Pulse Characteristics: Power Line Example.

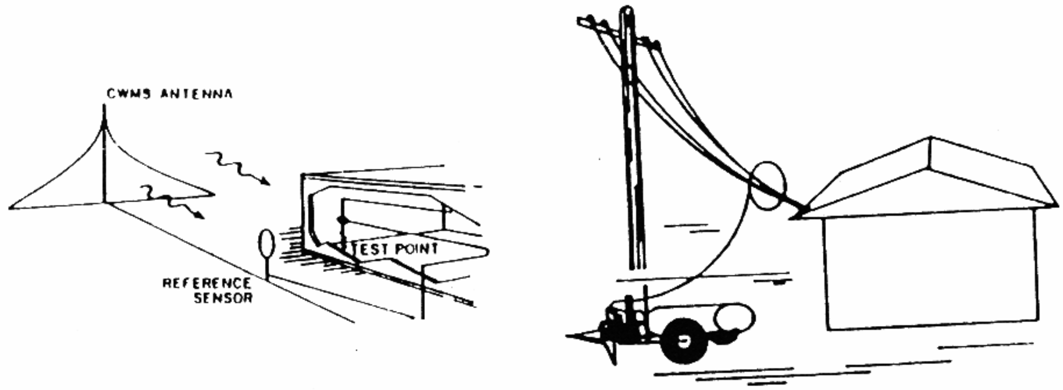

Figure 3. Low Level + Pulsed Current Injection

The CW/PCI hardness test approach has been used most extensively for tests of hardened C3 facilities, recent examples including the Alternate National Military Command Center and the STRATCOM JRSC earth terminal complex. MIL-STD-188-125 requires two CW/PCI tests for such facilities, referred to as the acceptance test and the verification test. The acceptance test is conducted on the bare facility after all related construction work is completed. Verification testing is conducted once installation and operational checks of facility electronics are complete. The verification test includes time urgent mission functional checks during PCI and thus requires the system to be up and operating during the test.

Summary.

Integrated, operational system EMP testing is required for reasonable confidence in any system's EMP hardness. We cannot validate hardening by analysis or inspection. Test capabilities exist to validate the EMP hardness of properly designed systems. High level free-field simulators are the means of choice for testing aircraft and ground mobile systems. Combination low level CW and PCI testing are preferred for testing fixed facilities and systems with long lines. For other than low risk hardened systems, only limited assessment (as opposed to hardness verification) is possible.