ELECTROMAGNETIC PULSE (EMP)

Introduction

Of the four basic environments which result from the detonation of nuclear weapons (blast, thermal, transient radiation, and EMP), it is EMP that is most widely threatening to unprotected electronic equipment. The geographic range of electronic vulnerability to EMP can extend many orders of magnitude beyond that of the other nuclear environments. In the case of a high altitude detonation (1 megaton weapon at approximately 300 miles), the entire continental United States would be affected by EMP with little other indication that a nuclear event had taken place. EMP does not constitute a threat to human life, but can cause burnout or upset in electronic devices.

EMP is the most consistently specified environment in the nuclear hardening of military electronic equipment. A growing concern is also being voiced by the commercial electronics community and public services over vulnerability of their systems. The most critically affected of non-military electronics systems users are telephone and emergency communications services, power companies, airlines, and medical facilities.

Source Mechanism

Although EMP comes as a result of nuclear weapon detonation, it is actually a secondary effect. Ionizing radiation from the weapon burst (X-rays and Gamma rays) interact with the gases and particulate matter that make up the earth's atmosphere, to generate the resultant electromagnetic field. The transfer function for this phenomenon is referred to as the Compton effect. Loosely defined, the Compton effect is the interaction between an ionizing photon and an electron, such that the electron is accelerated with respect to its initial equilibrium and a secondary photon of lesser energy (longer wavelength) is generated. The accelerated electron (originally from an air molecule or dust particle) is deflected by the earth's magnetic field and produces an oscillation at EMP frequencies. The atmospheric zone where ionizing radiation generates EMP is referred to as the source region.

The exact characteristics of EMP generation are complicated and depend upon the burst altitude, weapon yield, and atmospheric pressure. The following parameters, however, will typify the threat encountered by electronic systems in aeronautical, surface marine, and surface land based applications.

Field Strength. EMP energy can reach E field intensities of 10^5 volts per meter with an accompanying H field intensity of 266 amps per meter based on free space impedance.

Spectrum. Damaging levels of EMP generally reside within the bandwidth from 10 KHz to 100 MHz and have peak amplitude between one and ten MHz. EMP arrives as a massive noise pulse having transient frequency components of the spectrum as dampened sinusoids.

Polarization. High altitude EMP arrives as a horizontally polarized descending plane wave from the source region. Ground level generated EMP arrives as a vertically polarized plane wave with a high tangential magnetic field near the source region.

Pulsewidth. As characterized by its spectrum, EMP has a risetime of a few nanoseconds. The duration varies, depending on origin. High altitude EMP has an effective pulsewidth of a few microseconds. Ground level EMP, due to the reactive nature of the dense atmosphere, may sustain for ten or more microseconds, but with reduced field level as compared to high altitude EMP.

Illumination. Coverage is dependent upon burst altitude. A ground burst may present damaging EMP within a 10 mile radius, whereas the same weapon may expand this illumination to a 1000 mile radius with a high altitude burst.

Damage Mechanism

Damage in electronic equipment, due to EMP, manifests in two effects. The first effect is hardware damage, usually in the form of semiconductor burnout. The second effect is electronic upset, usually in the form of data transmission loss or loss of stored data.

EMP couples into electronic equipment by three different paths. The first path is through deliberate antennas used for RF transmission. In general, antennas having a rejection bandwidth below 100 MHz will filter out damaging EMP energy. Any transient sensitive device, however, such as a microwave detector diode, which is directly in line from a deliberate antenna, should be suspected as vulnerable, regardless of operating frequency.

The second coupling path for EMP is non-deliberate antennas. These antennas may be in the form of power lines, data transmission lines, mechanical shafts, or metallic coolant tubing. Any conductive appendage to an electronic equipment item that is not first electrically bypassed or decoupled in the EMP bandwidth prior to entry into the equipment item can constitute a non-deliberate antenna.

The third EMP coupling path is direct penetration into the electronic equipment item. It may either be diffusion of energy through non-effective shield walls or propagation of energy through apertures. Non-effective shield walls may consist of walls which are conductive, but too thin to stop low frequency magnetic waves. They may also be walls that are low in conductivity, thereby constituting a transfer impedance to external surface currents. Apertures in equipment item enclosures consist of any non-conductive openings or slits that will allow a re-radiation of incident EMP energy within the enclosure.

General Hardening Guidelines

The following guidelines are presented to provide the designer with basic solutions when a vulnerability to EMP has been isolated. Careful analysis of each possible EMP penetration, along with testing of the final design, are ultimate requirements for assurance of EMP hardness without costly over-design.

1. Employ conductive metallic enclosures for equipment. Electrically bond all seams and minimize the dimensions of non-conductive openings.
2. Employ electrically sealed chambers behind displays or other interfaces that require large openings in the equipment enclosure. Place EMP protection devices, which are subject to radiating high voltage or current transients, in separate chambers bonded to exterior walls.
3. Employ close braid shields or continuous foil shields over interface wires that cannot be otherwise protected from EMP. Terminate all EMP shields at the periphere of enclosures. Use conductive backshells on connectors for shield termination.
4. Filter interface lines that do not operate in the EMP spectrum. Select filter designs that will not breakdown due to EMP transients.
5. Limit voltage or current parameters on interface lines that must operate in the EMP spectrum. Series or shunt resistors and zener diodes or transient suppressors can be used.
6. Isolate interface electronics from sensitive internal circuitry such as microprocessors or random accessor memories. Prevent internal enclosure ground loops from carrying bypassed EMP transients.
7. Avoid the use of MOS devices or latchup prone devices in interface circuits.
8. Where data upset cannot be tolerated, use twisted shielded pairs with high level common mode termination, redundant data transmission, or fiber optic links at interfaces.
9. Use spark gaps on RF antenna transmission lines that operate in the EMP spectrum.
10. Employ Faraday shielded transformers where transformers are necessary, such as audio or pulse interface lines.

In general, EMP protection should coordinate with good EMI, EMC, and EMV (lightning) designs. Measures that avoid separate treatments for similar transients are cost effective.

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EMP SUSCEPTIBILITY ANALYSIS

Introduction

Nuclear weapon generated electromagnetic pulse (EMP) fields can be a serious threat to electronic systems.

EMP fields incident on electronic systems interact with system enclosures, cabling and antennas producing transient voltages and currents at system interface pins and in interior circuits. The induced EMP transients may cause two types of detrimental responses—either upset or damage.

Upset is the generation of false signals which can cause a system to take undesired actions. Damage refers to the degradation of a component to the point where it can no longer meet its design function criteria.

The EMP voltages and currents (and their associated time behavior) must be known at the circuit level in order to perform circuit analysis. Often the EMP specification is given in what is called a pin specification, which is the worst-case EMP voltages and currents that may appear at any I/O pin. The pin specification usually is defined in terms of a Thevenin equivalent source with a specified frequency and time behavior applied between each I/O pin and the lowest impedance return. Also the EMP specification often includes a surface current requirement for system components (blackboxes). The effect of this current on the internal circuitry must be determined via a penetration and coupling analysis. Once the EMP-induced voltages are known, the susceptibility analysis can then be carried out.

EMP susceptibility analysis is the systematic process for determining the hardness of electronic circuits to EMP-induced transients.

Susceptibility analysis evaluates the relative hardness of system components and circuits to EMP-induced upset and damage. The concept of design margin (DM) is used as the relative measure of EMP hardness. The design margin is a measure of the ratio of the amplitude threshold level required to cause damage or upset to the specified EMP environment level. When the circuit or component degradation threshold exceeds the EMP threat level with an adequate margin, no further analysis or hardening action is necessary. If the EMP threat level is close to the minimum threshold, then more refined analysis or EMP hardening action is required. Components or circuits with an adequate design margin are designated Category 2. Those with an inadequate design margin are designated Category 1.

A susceptibility analysis consists of six phases which are: data collection, susceptibility screening, detailed analysis, vulnerability classification, EMP hardening, and determination of hardness margin reliabilities and confidence levels.