

# Electromagnetic Pulse (EMP) Effects on Electronic and Electrical Systems

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## OVERVIEW

An electromagnetic pulse (EMP) is a high amplitude, short duration, broadband pulse of electromagnetic energy, which can have devastating effects on unprotected electrical and electronic equipment and systems. The increased use of electronics in our everyday lives has augmented system vulnerability to the effects electromagnetic fields, specifically the effects of High altitude Electromagnetic Pulse (HEMP).

Reducing the impact of potential EMP attacks on electronics begins with design. As such, protecting equipment, systems, and infrastructure is dependent upon rigorous testing and certification to ensure their ability to withstand the effects of EMP.

## UNDERSTANDING HISTORY

EMPs were discovered by the US over the course of five high-altitude atomic bomb tests (Dominic I/Fishbowl) conducted July 9 through November 4, 1962. Most notable was the starfish prime test event. Objectives were to evaluate the physical effects of high altitude nuclear detonations on incoming ICBMs, and to assess the vulnerability of US outgoing ICBMs, long range DoD communications systems, as well as the feasibility of testing nuclear weapons in outer space.

The 1.45 MegaTon atomic payload was launched from Johnston Island and detonated at an altitude of 400 Km over the Pacific Ocean, more than 700 miles away from Honolulu, Hawaii. At this distance, the physical shockwave and blast effects were not a concern and only visible light was observed. However, the resulting electromagnetic pulse was much greater than expected; disrupting Hawaiian radio stations, damaging electrical equipment, and burning out over 300 street lights.

## HIGH ALTITUDE ELECTROMAGNETIC PULSE (HEMP)

HEMP is caused by a nuclear burst at high altitudes. High energy photons (primarily gamma rays) are released in all directions from the detonation. These photons in turn produce high energy free electrons within the earth's ozone layer (roughly an altitude between ~ 20 and 40 km above sea level). This energy conversion process known as Compton effect, or Compton scattering.

## COMPTON EFFECT

As high energy photons enter the ozone region of the atmosphere, they collide with molecules (oxygen, nitrogen and other atoms) transferring some energy to their loosely bound electrons, making them recoil from their nucleus. After the collision, the photon's trajectory is changed (or scattered) based on the angle of the incident. On this new course, the photon may repeat this process until all remaining energy is dissipated.

Within the ozone region (~ 20 km – 40 km), the recoiled electrons become trapped in the earth's magnetic field, resulting in a very large, fast-rising electromagnetic pulse. The exposure radius, referred to as the "disposition region," is determined by three main elements:

1. Height of the blast
2. Size of the blast (payload)
3. Kinetic energy of the blast (energetic type)

In general terms, the higher the explosion, the greater the disposition region becomes. Theoretically, the size of the EMP disposition region is only limited by the curvature (horizon) of the planet.

A high altitude nuclear EMP is a complex multi-pulse waveform typically defined in terms of three components. Although the actual characteristics of these components are nationally classified under MIL-STD-2169, an unclassified version has been developed by the IEC (IEC 61000-2-9). The three components are defined as:

- E1 Early time
- E2 Intermediate time
- E3 Late time

#### ***E1 Early Time - Prompt Gamma Pulse***

E1 is a fast component of an EMP at 2/50 nsec pulse. The peak value up to 50,000 volts per meter and occurs too quickly for lightning protection devices to react. In fact, it can temporarily or permanently disrupt the operation of electronic devices due to high induced voltages and currents. In addition, it couples well to local antennas, equipment in buildings (through apertures), and to short and long conductive lines. The most common protection against the effects of E1 is accomplished using electromagnetic shielding, filters, and transient surge arresters.

#### ***E2(a) Intermediate Time - Scattered Gamma Pulse***

E2(a) that is produced from scattered gamma rays represents an intermediate time at 1.5/5000  $\mu$ sec pulse with a peak value 100 volts per meter. It's similar to a pulse produced by nearby lightning. In addition, it couples well to long conductive lines, vertical antenna towers, and aircraft with trailing wire antennas. Protection is accomplished using EM filters and surge arresters.

#### ***E2(b) Intermediate Time - Neutron Gamma pulse***

E2(b) that is produced from a neutron gamma pulse, which has up to -1 second peak value 10 volts per meter. It couples well to long overhead and buried conductive lines and to extended VLF and LF antennas. The dominant frequencies overlap AC power and audio spectrums, making filtering difficult. An E2 can create extensive damage to systems in which protection has already been impaired by E. It is least destructive due to wide use of lightning protection devices.

#### ***E3 Late Time - Magnetohydrodynamic (MHD) Pulse***

E3 is a slow pulse, which can last up to 50 minutes 100 volts per meter. This is similar to geomagnetic solar storm. This component's duration allows it to create disruptive currents in electricity transmission lines. The E3 pulse produces ground-induced current (DC) in conductors; hundreds to thousands of amperes. It results in wide-scale damage to electrical supply and distribution systems tied to these line and couples well to power and long communications lines including undersea cables. The low frequency content (sub Hertz) makes shielding and isolation difficult

### **WEAPONIZED EMP TECHNOLOGY**

Highly effective non-nuclear EMP technologies are progressively being developed worldwide. Classified as "Direct Energy Weapons," these technologies are now being used by US armed forces and state and local police departments.

Direct energy weapons are designed to simulate the electromagnetic environmental effects of conventional HEMP at

distances < 500 feet, ranging from operational disturbances to permanent damage. A prime example of this technology is the “arc discharge” EMP generator:

- High voltage capacitors deliver massive amounts of current across a thin, underrated conductor to a low impedance load or short circuit
- The wire acts like a fuse opening at the peak of high current discharge of the capacitor, resulting in a massive release of a broadband electromagnetic energy pulse
- A small parabolic reflector directs and focuses pulsed energy towards a target

Another example of non-nuclear EMP technology is the Flux Compression Generator (FCG). The FCG was first demonstrated by Clarence Fowler at Los Alamos National Laboratories (LANL) in the late 1950s.

- Injects a high-energy pulse into a large conductive coil
- At the point of peak pulse current, a small explosive charge is deployed; quickly compressing the coil to one end of the generator and creating massive amounts of electromagnetic energy
- Initial designs were several feet in length, but through technological advances, are now reported to be roughly the size of a beer can
- Modern designs are reported to induce magnetic field levels between 30 kA and 120 kA for durations up to half a millisecond

The US Navy reportedly used a FCG pulse weapon during the opening hours of the Persian Gulf War to effectively destroy vast amounts of Iraqi electronics, power, and telecommunications systems quickly and efficiently. The deployment of EMP weaponry instantly caused the “Fog of War” (complete loss of communications between troops and command posts), and essentially ended the war before it began.

### ***Common Electromagnetic Pulse Test and Protection Design Guides***

The following list provides common testing standards for protecting against electromagnetic pulses:

- MIL-STD-2169B HEMP Environment (Classified)
- MIL-STD-188-125-1 HEMP Hardening Fixed Facilities
- MIL-STD-188-125-2 HEMP Hardening Transportable Systems
- MIL-STD-461 EMI Requirements Subsystems
- MIL-STD-464 EMI Requirements for Systems (Electromagnetic Environment Effects)
- TOP 01-2-620 High Altitude Electromagnetic Pulse Testing
- NPFC - MIL-STD-3023 High-Altitude Electromagnetic Pulse (HEMP) Protection for Military Aircraft
- IEC 61000-2-9 Electromagnetic compatibility (EMC) HEMP Environment
- IEC SC 77C Commercial HEMP Requirements

### ***MIL-STD-461 RS105 EMP Testing***

The RS105 test method specified in MIL-STD-461G addresses the risk of radiated exposure to an EMP event. RS105 testing is generally applicable for equipment installed in exposed and partially exposed environments. The US Navy requires RS105 testing for nearly all installation platforms, surface ships, submarines, and aircraft-to-ground applications.

The RS105 test method is used to verify the subsystem's ability to withstand the electromagnetic effects of high amplitude fast transient electromagnetic fields. This test method:

- Simulates the electromagnetic effects of the E1 early time waveform
- Applies to electrical and electronic equipment with a high probability of being exposed to EMP
- Is located external to a hardened (shielded) platform or facility
- Applies to poorly shielded or unshielded platforms (shipboard wheel houses, hangars)
- Equipment is intended solely for use on non-metallic platforms (aircraft, ships, ground vehicles)
- Required when specified by the DoD procurement agency

RS105 evaluates the radiated coupling through equipment enclosure apertures. It is not intended to evaluate the effects of induced cabling coupling, including cable shield integrity, internal filtering or surge protection.

The effects of induced cable coupling are evaluated under MIL-STD-461 Test Method CS116. This includes the following:

- Unclassified pulse characteristics from IEC 61000-2-9 are used
- Rise time is 1 ns between 10% and 90% of peak
- Full width half maximum (FWHM) pulse width equal to  $23 \text{ ns} \pm 5 \text{ ns}$
- Test levels, up to 50,000 V/m are applied incrementally from 5 kV/m until either signs of degraded performance as observed or 50 kV/m is reached (whichever occurs first)
- 5 pulses are applied at a rate no greater than 1 ppm

The standard RS105 suggests a TEM cell, parallel transmission line, or other equivalent system to deliver the pulse. The pulse characteristics and field uniformity must be achieved. In addition, the EUT is centered within the working volume of the radiation system so it does not exceed the usable volume of the radiation system ( $h/3, B/2, A/2$ )/(EUT dimensions x,y,z).

### ***Free Field Electrical Field Monitor***

The electric field monitor is used for the measurement of the electric component of the electromagnetic field.

- A free-space, high frequency D-dot sensor measures the time rate of change of electric displacement.
- Free field D-Dot's include two passive asymptotic sensing elements accurately positioned on opposite sides of a common ground plate and have a radial output direction.

$$V_o = R A_{eq} dD/dt$$

$$V_o = \text{Sensor output (volts)}$$

$$R = \text{Sensor load impedance (100}\Omega\text{)}$$

$$A_{eq} = \text{Sensor equivalent area (m}^2\text{)}$$

$$D = \text{magnitude of electric displacement vector (D = } \epsilon_0 E \text{ in Coul/m}^2\text{)}$$

### ***Speak to an Expert***

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