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Critical Design Issues in Protecting Against EMP and HEMP

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EMC LIVE 2014

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What is EMP/HEMP?

EMP – Electromagnetic Pulse

- Nuclear detonation on or near earth's surface
- Also called Transient Electromagnetic Disturbance
- Burst of Electromagnetic Radiations/Energy
- Depending on the source - Radiated Electric or Magnetic Field or Conducted Electrical Current
- Induces Electrical Current and Voltage stresses on and within systems
- Can ignite Electro-explosive devices or fuel stores

HEMP – High Altitude Electromagnetic Pulse

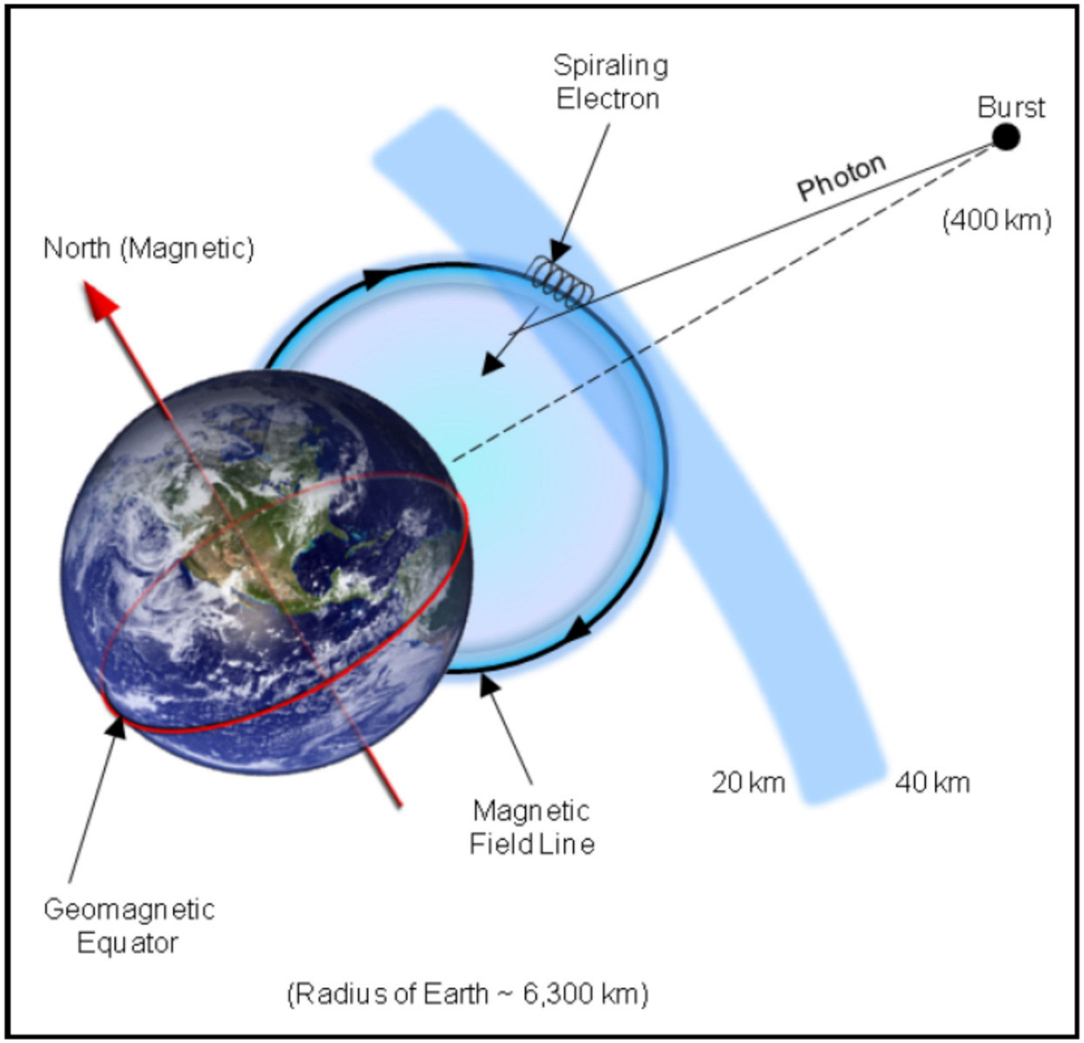
- An intense, time varying, Electromagnetic Pulse (EMP)
- Caused by nuclear detonation in or above the earth's atmosphere
- Line of sight effect

What is EMP/HEMP?

HEMP…

- Device energy, mainly due to Gamma Rays, is deposited in the atmosphere at altitudes between 20 km and 40 km.
- Propagates to all points in the air and on the ground in line-of-sight of the burst with little attenuation.
- A single high-altitude burst can produce HEMP fields over millions of square kilometers on the earth’s surface.
- HEMP field can rise up to 50 kV/m peak within a few nanoseconds; it then decays gradually over a period lasting hundreds of seconds.

What is EMP/HEMP?



Formation of HEMP (TOPS 01-2-620 HEMP Testing)

What is EMP/HEMP?

Nuclear event

↓

Gamma Radiations

↓

3 Waves of Electromagnetic Pulse

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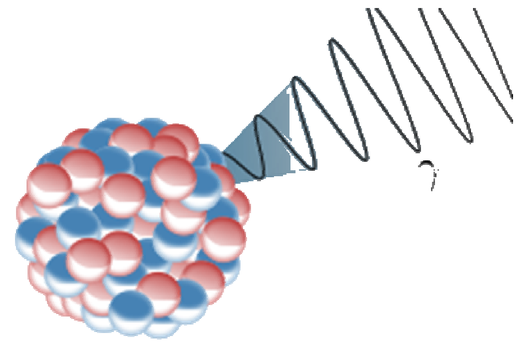
Induces extremely high voltages and currents into electrical and electronic systems

↓

Destroys most unprotected electrical, electronic and power systems

Gamma Rays

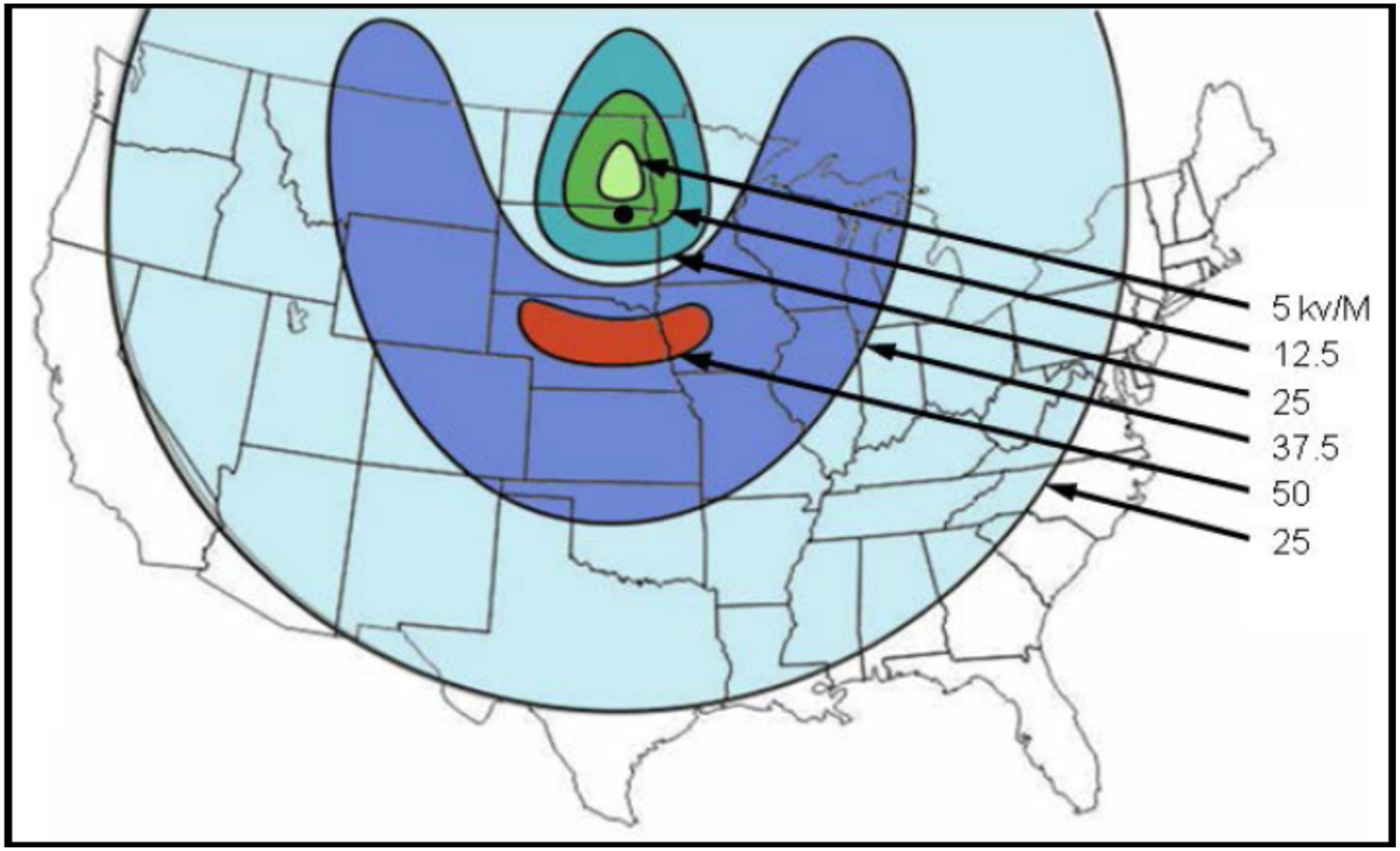


- Packets of Photons carrying Electromagnetic Energy
- Extremely high frequency (10 exahertz or > 10^{19} Hz)
- Smallest wavelength (10 picometer) in entire Electromagnetic Spectrum
- Can pass through an atom (any material)
- Very high energy per Photon (100 keV – 10MeV)
- Ionizing radiations – Can dislodge electron from an atom
- Ionizing natures makes them biologically hazardous

HEMP Threat

EMP Area By Bursts at 30, 120 and 300 miles
Gary Smith, "Electromagnetic Pulse Threats," testimony to House, National Security Committee on July 16, 1997

HEMP Threat



Generated E-Field Contours at the earth's surface from HEMP
(TOPS 01-2-620 HEMP Testing)

HEMP Threat

According to a survey of 85 arms experts in June 2005:

- “There is a 70 percent risk of an attack somewhere in the world with a weapon of mass destruction in the next decade”.

The survey executor, U.S. Senate Foreign Relations Committee Chairman Richard Lugar, described:

- “The Weapons of Mass Destruction (WMD) threat is real and increasing over time.”

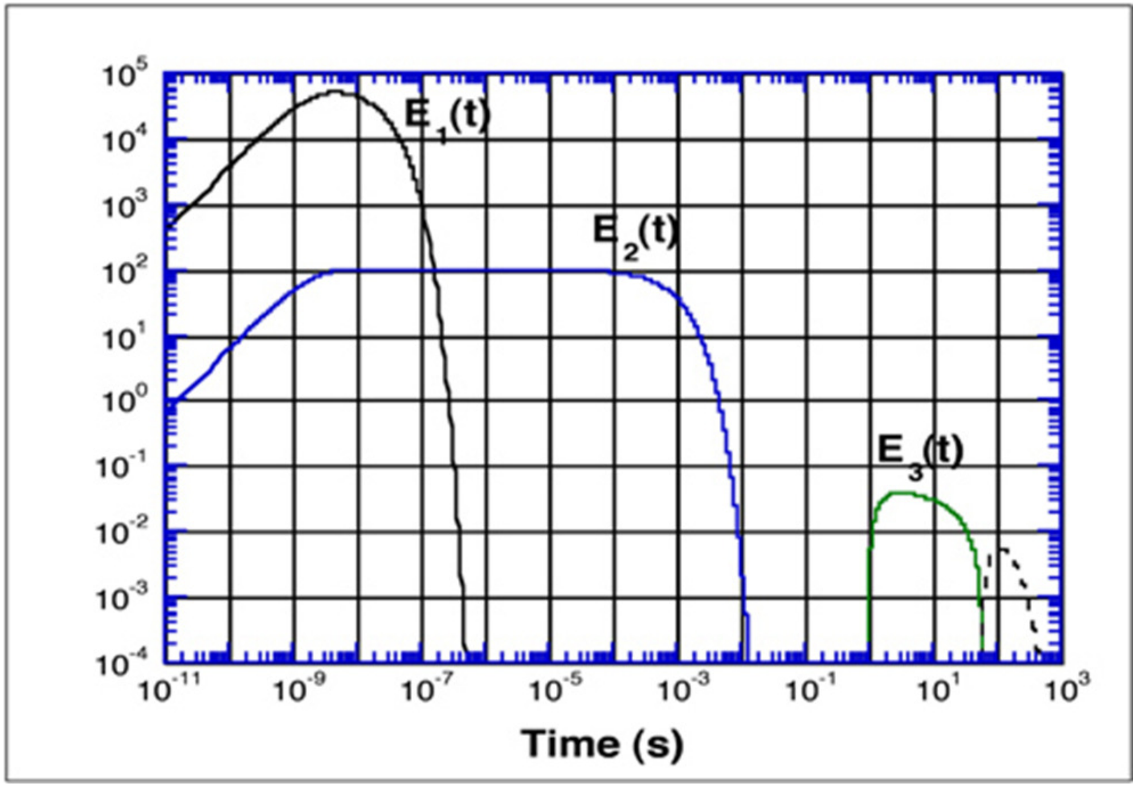
Geomagnetic Storms

- Large increase in charged particles ejected from the Sun and into the solar wind.
- Interact with the Earth's Magnetic Field and produce a significant distortion of the Geomagnetic Field on the Earth's surface.
- This rapid variation of the Geomagnetic Field (on the order of seconds to minutes) induces Time Varying Electric Fields in the Earth, which through the <u>neutrals</u> of transformers create time-varying (but quasi-dc relative to 60Hz) currents in the high-voltage power network.
- These currents induce severe harmonics, increase inductive load and produce heating in each exposed transformer.
- This can lead to voltage collapse of the network as experienced by the power grid in Quebec in March 1989 and damage to highly exposed transformers (6 million people lost power)

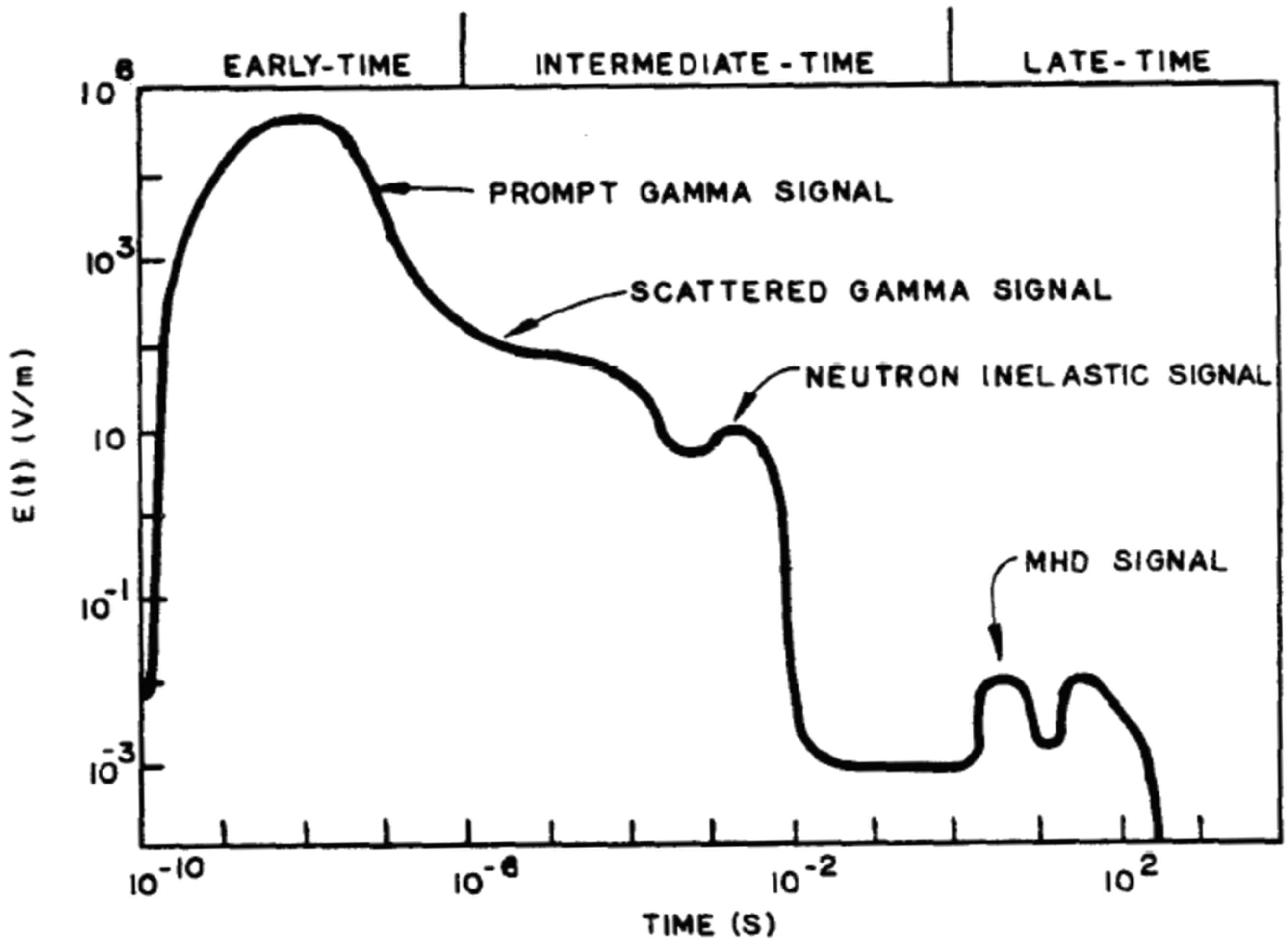
HEMP Waveform

Three distinct components of an electromagnetic pulse (MIL-STD-464)

- Fast
  - E1
  - 20/550 ns pulse
  - 50KV/m peak
- Medium
  - E2
  - 1.5/5000 μs pulse
  - 100V/m peak
- Slow
  - E3
  - 0.2/25 s pulse
  - 40V/m peak



Different Time Phases of HEMP



Impact of EMP/HEMP

Type	Features	Systems impact
HEMP	Large extent, high amplitude, broad frequency band, plane wave	Most widely specified threat
Surface-burst		
Source region	Large amplitude, limited extent includes varying conductivity, currents	Important for systems which are hard to other nuclear effects
Radiated region	Large amplitude varies inversely with distance	Can supersede HEMP if vertical orientation or low freqs. important
Air-burst		
Source region	Similar to surface-burst	See surface burst
Radiated region	Amplitude less than HEMP	Superseded by HEMP
SGEMP	Very high amplitude and fast rise time	Important for exoatmospheric systems
MHD-EMP	Very low frequency, low amplitude, large extent	May affect long-land or submarine cables

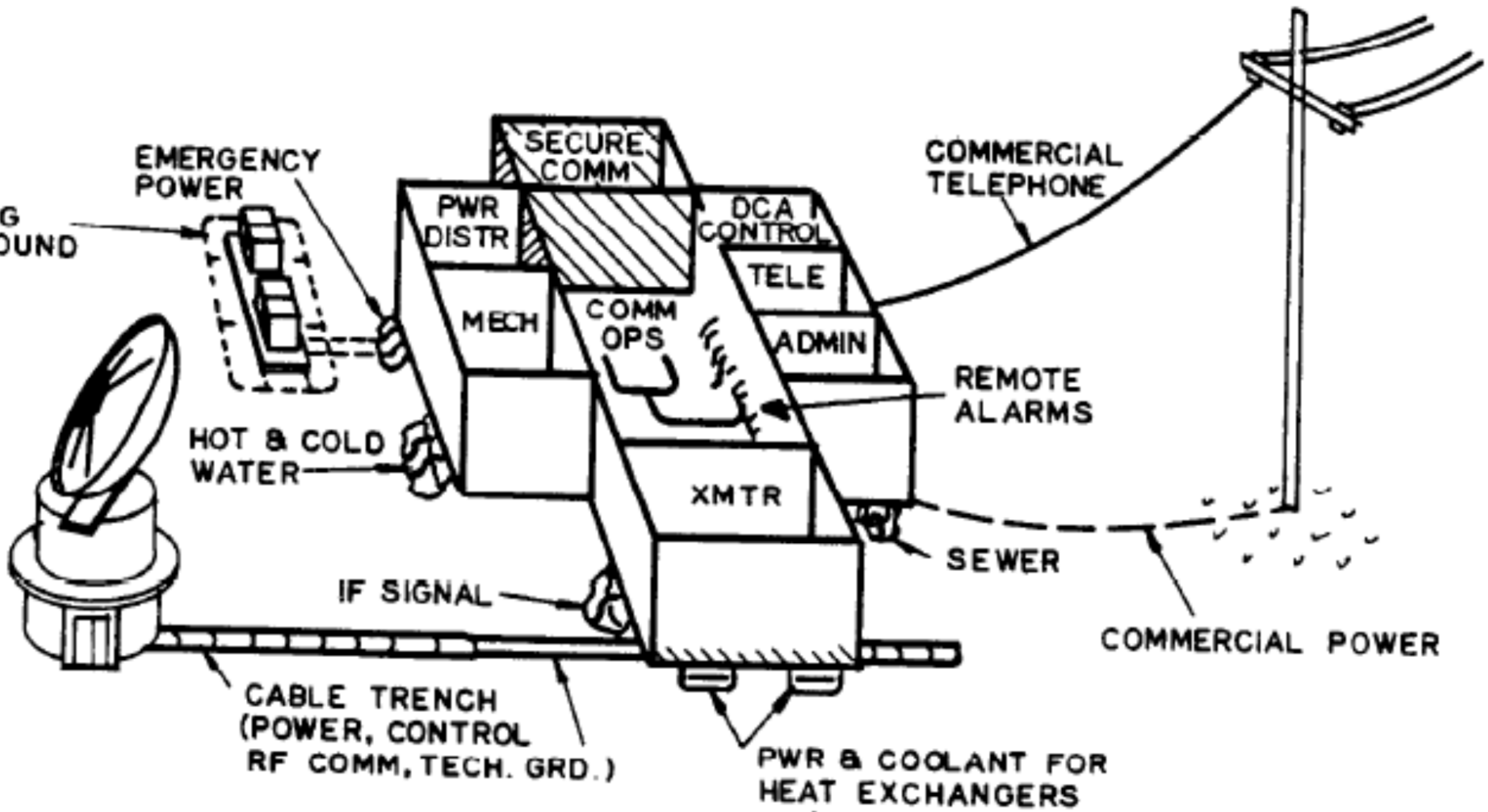
*Source: ref 2-1, DNA EMP Course Study Guide, draft prepared for Defense Nuclear Agency (The BDM Corp., April 1983), p I-51.

Impact of EMP/HEMP

Type	Peak amplitude	Timeframe
HEMP	50 kV/m	Few nanosec to 200 nanosec
Surface-burst		
Source region	1 MV/m	Few nanosec to 1 microsec
	10 kV/m	1 microsec to 0.1 sec
Radiated region	10 kV/m	1 microsec to 100 microsec
Air-burst		
Source region	Similar to surface-burst	
Radiated region	300 V/m at 5 km, typical (highly dependent on HOB	10 nanosec to 5 microsec
SGEMP	100 kV/m	Few nanosec to 100 nanosec
MHD-EMP	30 V/km	0.1 sec to 100 sec

*Source: ref 2-1, DNA EMP Course Study Guide, draft prepared for Defense Nuclear Agency (The BDM Corp., April 1983), p I-49.

Impact of EMP/HEMP



Ground Based Facilities – Unintentional Antennas

Impact of EMP/HEMP

E1 Pulse - Fast Component

- 20/550 nsec pulse - Electromagnetic Shock-wave
- Travels at the speed of light
- Peak value up to 50,000 volts/meter
- Too fast for Lightening Devices to react.
- Will temporarily or permanently disrupt the functioning of electronic devices due to high induced voltages and heating (communications equipment, protection systems, controls, sensors, cell phones, computers, cars and airplanes etc.)
- Occurs simultaneously over a large area
- The extent of the damage is determined by the altitude of the explosion.

Impact of EMP/HEMP

E2 Pulse - Medium Component

- 1.5/5000 μsec pulse
- Peak value 100 volts / meter
- Similar to pulse produced by Lightening
- Covers roughly the same geographic area as the Fast wave
- The peak power level of its electrical shock would be far lower.
- Follows the “Fast Component” by a fraction of a second
- Can potentially create extensive damage to systems already whose protection has already been impaired by the Fast wave.
- Least destructive due to wide use of Lightening protection devices

Impact of HEMP

E3 Pulse - Slow Component

- 0.2/25 sec pulse
- Peak value 40 volts/meter
- Also call MHD-EMP - Result of the earth's magnetic field being pushed out due to hot ionized gases from explosion and then restored in place
- Similar to Geomagnetic Solar storm
- Electrical voltage amplitudes much lower than E2 wave
- Due to duration of this component, creates disruptive currents in electricity transmission lines
- Produces Ground induced current (DC) in conductors, hundreds to thousands Amperes
- Results in wide scale damage to electrical supply and distribution systems tied to these lines.

Impact of EMP/HEMP

- A voltage induced between conductors can drive a surge current into an electronic circuit
- And a current induced onto a conductor can create a voltage across a series impedance across the circuit.
- It is almost impossible to neutralize the current as it surges into an electronic circuit.
- Fuse and circuit breakers have far slow response to prevent the current from flowing.
- Even if these do open, the circuit becomes nonfunctional until the interrupting device is reset.
- Effectively limiting the transient voltage near the sensitive electronics is the key to mitigating transient damage.

Loss due to HEMP

HEMP Tests

- US (Starfish), 1962
  - 1.44MT yield
  - 250 miles altitude over Johnson Island (South Pacific)
  - 5.6KV/meter E1 pulse in Honolulu, 800miles away
  - Some streetlights became non functional, Shut down of long distance telephone lines, disruption in microwave communications, malfunction of burglar alarms
  - Disabled 3 satellites in low earth orbit and damaged solar array of 7 satellites

- USSR (Test 184), 1962
  - 300KT yield
  - 180 miles altitude over Kazakhstan
  - 1000 to 1300 nTesla/min, E3 pulse
  - 2500A current was induced in overhead phone lines
  - 600 mile underground power line was knocked out
  - Power station 300 miles away set on fire by E3 pulse in 10 sec
  - Various devices malfunctioned or damaged / destroyed in 600 miles radius.

Loss due to HEMP

- Emergency system – Critical equipment that link First Responders to the Command System, if unprotected

- Critical unprotected infrastructure facilities, vital part of everyday life.
  - Emergency Facilities
  - Electric Power Facilities
  - Communications Facilities
  - Oil Refineries
  - Water Treatment Plants
  - Banking Systems
  - Transportation Systems
  - Pipelines
  - Food Production and Distribution
  - Medical Facilities

Specification for HEMP Protection

• 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 – Lightening, EMP etc.)
• IEC SC 77C	Commercial HEMP Requirements

Specification for HEMP Protection - MIL STD 188-125

- Calls out for EMP mitigation for all military C4 systems
  - Command
  - Control
  - Communications
  - Computer

- Designates applications which are included in EMP/ HEMP requirements, examples -
  - Subscriber Terminals
  - Data Processing Centers
  - Communications - Transmitting and Receiving Stations
  - Relay Facilities

- Applies to “both new construction and retrofit of existing facilities”

Specification for HEMP Protection - MIL-STD-188-125

- Shielding Effectiveness (SE) - To demonstrate the compliance of a facility and POE apertures with the shielding performance required

- Pulse Current Injection (PCI) testing techniques to demonstrate the integrity of the protection system.
  - Peak levels are specified for different applications under the standard (cable length, fixed vs. mobile systems, etc.)

- Transient protection solutions to mitigate lightning (E2) transients (8/20 μs)

- Protection for Power Grid Transients (10/1000 μs)

- Continuous Wave Immersion (CWI) - Exposure of the system to a threat level EMP using a pulse simulator. Performed with a low level field in the frequency domain and measuring the residual fields, charge/current densities and currents inside the facility while sweeping in the frequency domain on the whole EMP spectrum

Specification for HEMP Protection - IEC SC 77C

- Standards developed thus far by SC 77C for HEMP describes
  - The effects of HEMP on systems (IEC 61000-1-3)
  - Different types of Radiated and Conducted HEMP environments that may be produced (IEC 61000-2-9, -10, -11)
  - Different test methods for checking the HEMP Immunity (or Susceptibility) of equipment or systems (IEC 61000-4-23, -24, -25, -32)
  - General protection methods for intense electromagnetic fields (IEC 61000-5-3, 4, 5, 6)
  - Generic HEMP standard for protecting electronic equipment inside of different types of buildings (IEC 61000-6-6).

- Additional work is currently underway to standardize the method to protect distributed infrastructure systems to HEMP (61000-5-8) and to assess the HEMP hardness of a civil system (61000-5-9).

Specification for HEMP Protection - IEC SC 77C

EN61000-1 (EMC General)	-3 (HEMP Effects on Systems)					-5 (HPEM Effects on Systems)
EN61000-2 (EMC Environment)	-9 (HEMP Environment - Radiated)	-10 (HEMP Environment - Conducted)		-11 (Classification of HEMP Environment)		-13 (HPEM Environment Conducted and Radiated)
EN61000-4 (Testing and Measuring Techniques)	-23 (HEMP and other Radiated Disturbances, Protective Devices)	-24 (HEMP Conducted Disturbances, Protective Devices)		-25 (HEMP Immunity Equipment and Systems)	-32 (HEMP Simulator Compendium)	-35 (HPEM Simulator Compendium)
EN61000-5 (Installation and Mitigation Guidelines)	-3 (HEMP Protection Concepts)	-4 (Specifications for Protective Devices against HEMP Radiated Disturbance	-5 (Specification of Protective Devices for HEMP Conducted Disturbance)	-6 (Mitigation of External Influences)	-7 (Degrees of Protection Provided by Enclosures against Electromagnetic Disturbances)	
EN61000-6 (Generic Standards)	-6 (HEMP Immunity for Indoor Equipment)					

Seventeen publications prepared by IEC SC 77C dealing with HEMP, HPEM and general EM protection methods

Specification for HEMP Protection -Other Initiatives

- **ITU-T Study Group 5**
  - The International Telecommunications Union – Telecommunications Standardization Sector (ITU-T) has been working since 2005 to protect telecommunications and data centers from disruption from HPEM threats, which include HEMP and IEMI.
- **IEEE P1642**
  - The IEEE EMC Society with the support of TC-5 (HPEM) has been developing the "Recommended Practice for Protecting Public Accessible Computer Systems from IEMI.
- **Cigré C4 Brochure on IEMI**
  - The International Council on Large Electric Systems has formed a working group WG C4.206 entitled, "Protection of the high voltage power network control electronics against intentional electromagnetic interference (IEMI).

Protection Against EMP/HEMP

Hardening

Fixed ground-based command, control, communications, computer and intelligence (FGBC4I) systems require network interoperability during and after exposure to HEMP environments.

It is critical to have -

- Uniform and Effective Hardening
- Hardness Verification
- Hardness Maintenance
- Hardness surveillance

Protection Against EMP/HEMP

Hardening

- HEMP-hardened electrical parameter barrier for mission critical military operations to ensure system survivability during a HEMP event.
- An electromagnetic barrier that will prevent or limit HEMP or localized EMP fields or conducted transients from entering the shielded area.
- The shield and all points of entry (POE) must be treated properly to maintain shield integrity.
- Must be hardened to provide at least 80 dB attenuation in the plane wave field from 10 MHz to 1.5 GHz and magnetic attenuation of 2 dB at 1 kHz rising to 80 dB at 10 MHz in accordance with MIL-STD-125-1 and -2.

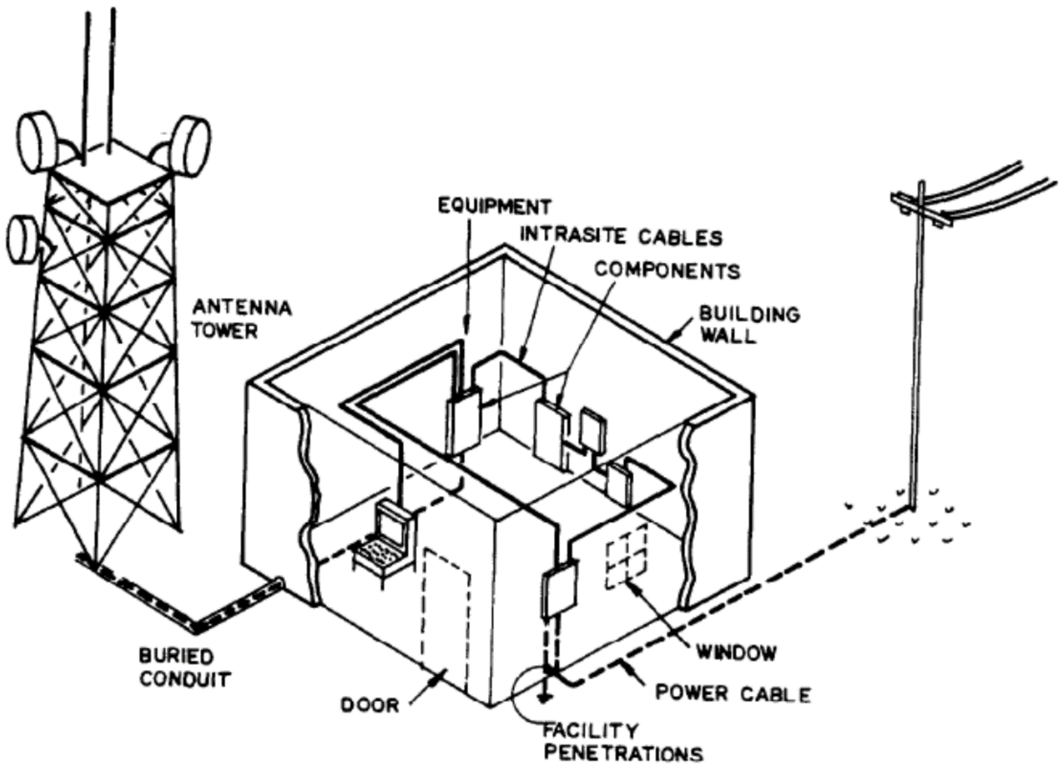
Protection Against EMP / HEMP

- Critical Facilities
  - Command
  - Control
  - Communications
  - Computer

- Critical Infrastructure
  - Communications - Transmitting and Receiving Stations
  - Subscriber Terminals
  - Data Processing Centers
  - Relay Facilities
  - Hospitals,
  - Labs
  - Power Plants
  - Power Distribution
  - Food Processing and Distribution

Protection Against EMP / HEMP

- Weak points in a building
  - Walls
  - Windows
  - Cables
  - Utility
  - Pipes



Protection Against EMP / HEMP

- Cost-effective shielding of high value assets

- Specific areas within a facility containing critical high value hardware, software, or other equipment should be hardened

- Consistent use of four element for hardening:
  - Shielding
  - Grounding
  - Filtering
  - Surge protection

- Emergency system - the vital equipment linking first responders to the command system must be shielded.

Protection Against EMP/HEMP

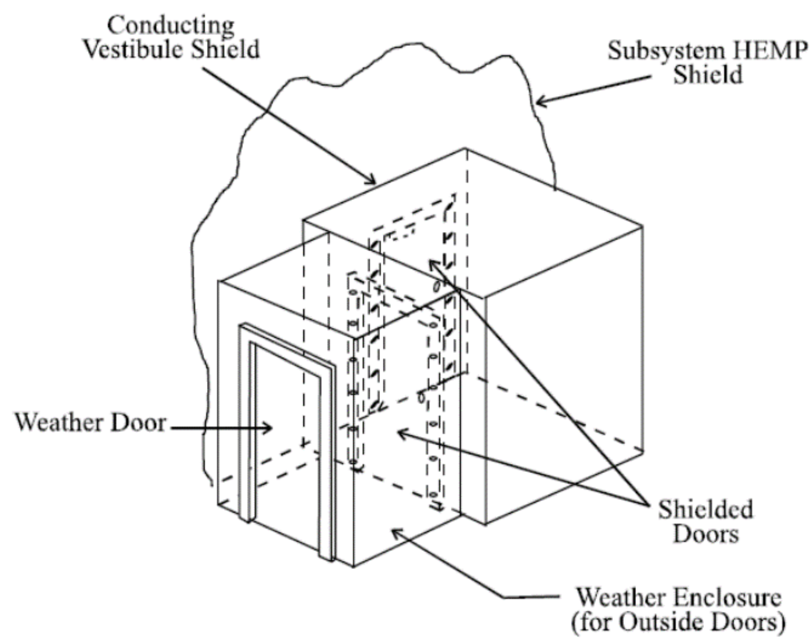
HEMP Shielding

- Some Protection – Concrete building (some protection)
- Good – Concrete + 30cm pitch Rebar
- Better – Concrete + 30cm pitch Rebar + Low Carbon Steel shield
- Best – Welded metal construction / Fully metal shielded.
- Mission Critical – Welded metal structure built underground (HEMP amplitude is decreased with depth inside the earth)

Protection Against EMP/HEMP

Hardness Critical POE's

- Door seams with continuous or maximum possible contact points
- Shielded vestibules with interlocked metal doors
- Waveguide entry ways
- Honeycomb vents
- Various pipe penetrations



Protection Against EMP/HEMP

Hardness Critical POE's

- Welded steel rooms or buildings
- Modular systems made of galvanized steel or copper-clad panels, and modular pan
- Minimum seams and good seam quality
- Fittings and coupling elements designed to prevent inadvertent gaps.
- Sub-assemblies for the various points of entry and egress
- Power and Signal Line Filters with EMP/HEMP Protection
- Fiber optic penetrations are all high speed data (HCI)

Protection Against EMP/HEMP

Shielding

- Modular shielding systems are available in single-shield copper, single shield steel, double-layer steel cell type, or steel pan form enclosures,

- Doors must provide a durable means for making repeatable seals around the entire perimeter. Shielded door performance should provide a safety factor of up to 20 dB both initially and after a reasonable number of cycles for all requirements up to 100 dB at 10 GHz.

- Small copper enclosures fitted with shock mounts that can be installed in all mobile field units. Emergency radios that need to be recharged can be placed in a secure shielded enclosure with a battery charging system

Protection Against EMP/HEMP

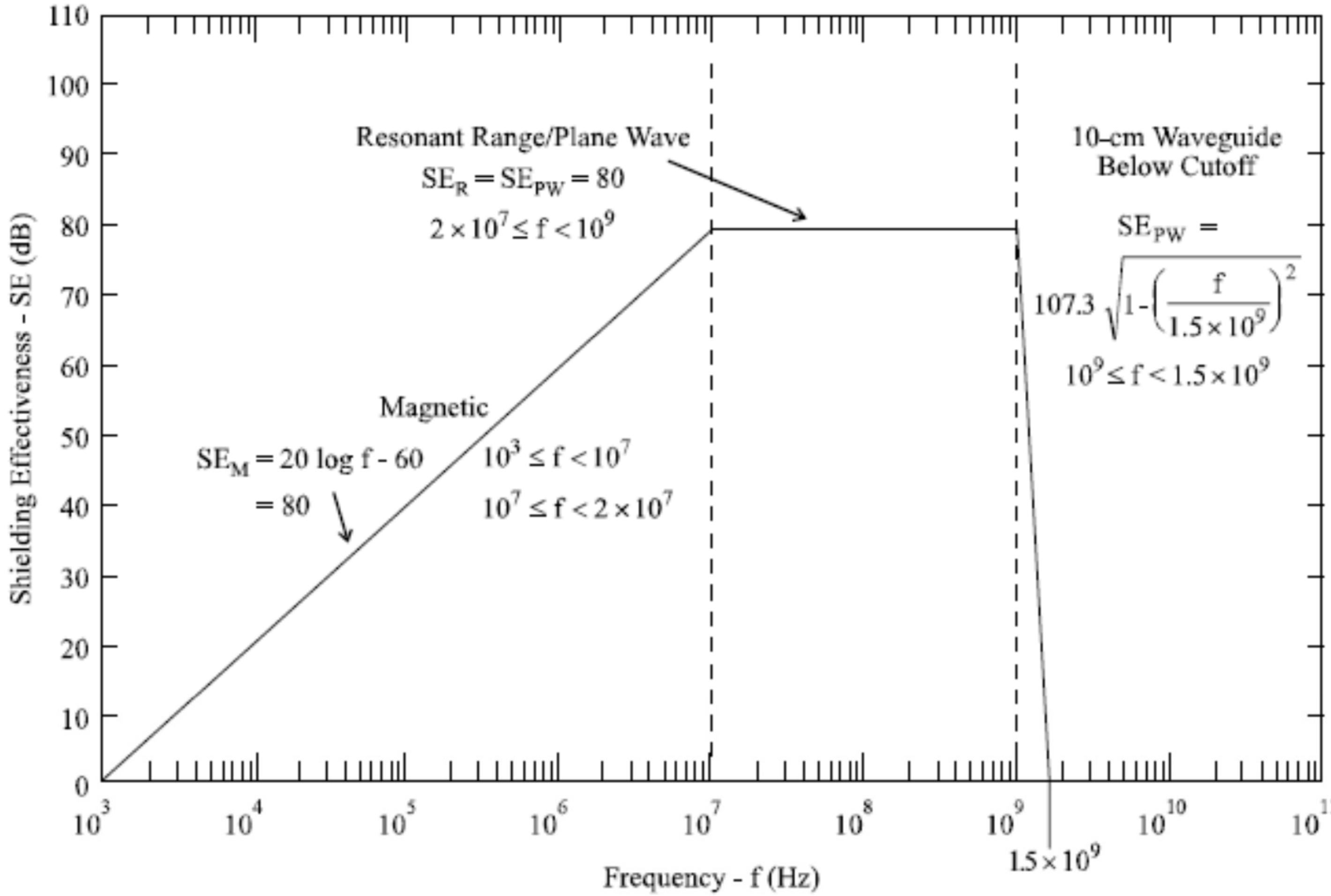


FIGURE 4. Minimum HEMP shielding effectiveness requirements (measured in accordance with procedures of Appendix A).

Protection Against EMP/HEMP

Shielding

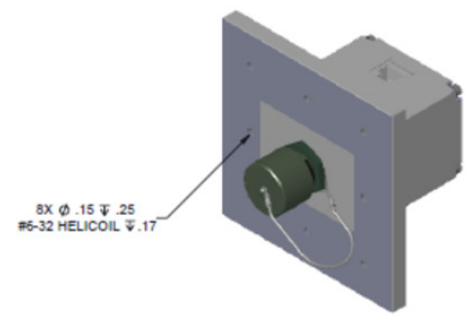
- The shield and all points of entry must be hardened to provide at least 80 dB of attenuation in the plane wave field from 10 MHz to 1.5 GHz and magnetic attenuation of 2 dB at 1 kHz, rising to 80 dB at 10 MHz.

- Proper shielding of the sensitive electrical and electronic systems prevents the propagation of induced voltages and currents past or around the filtering or protection schemes employed.

Protection Against EMP/HEMP

Penetration

- To maintain shielding effectiveness, using a combination of power line filtering combined with –
  - Electrical Surge Arrestors (ESA)
  - Metal Oxide Varistor (MOV),
  - Gas Discharge Tube Arrestors (GDT)
  - Silicon Avalanche Suppressor Diode (SASD) or



Transtector POE Transient Protection Module

- Other penetrations-
  - Waveguide below cut off
  - Fiber optics.

- Applying passive filter networks is extremely difficult with high frequency data circuits because the frequency content of the transient is similar to the data rate of the original signal.

- Signal line interfaces, penetrating the shield, should use a fiber optic system for optimum EMP security.

Protection Against EMP/HEMP

Grounding

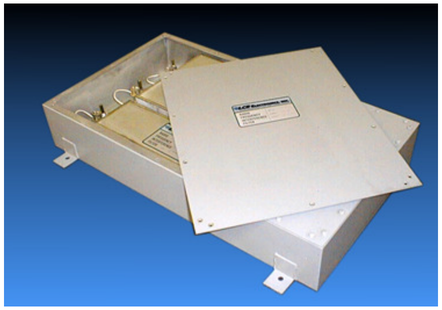
- Use Faraday cage
- Mount protection modules directly to Faraday cage ground structure.
- Many computer installations will even run two grounds –
  - The safety ground (required by NEC) and
  - A special insulated, isolated and dedicated “computer quality” ground (used as the zero reference for the computer’s DC power supply and logic)

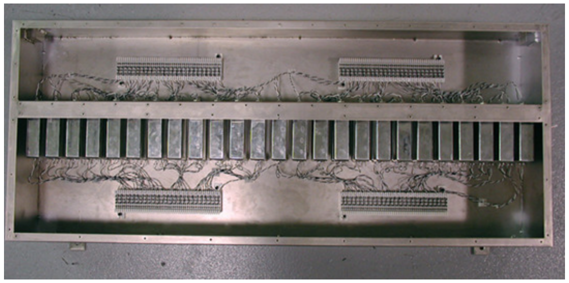
Protection Against EMP/HEMP

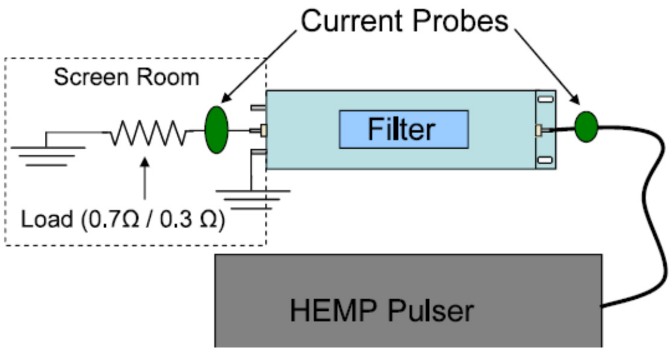
EMI Filtering with HEMP Protection

- 100dB @ 14KHz to 10GHz for power line filters.
- 100 dB extended to 40GHz with proper shielding
- Telephone and Signal line filters
- HEMP Protection modules connected line to ground for clamping down E1 and E2 pulse
- The maximum (worst case) values are typically used:
  - E1: 20/500 nsec, 2500A peak (Less than 10A residual current through 2Ω resistor)
  - E2: 1.5/4000 µsec, 250A peak (survive with no damage)
  - E3: 0.2/20s 1000A peak (only for systems connected to very long cables)

Protection Against EMP/HEMP



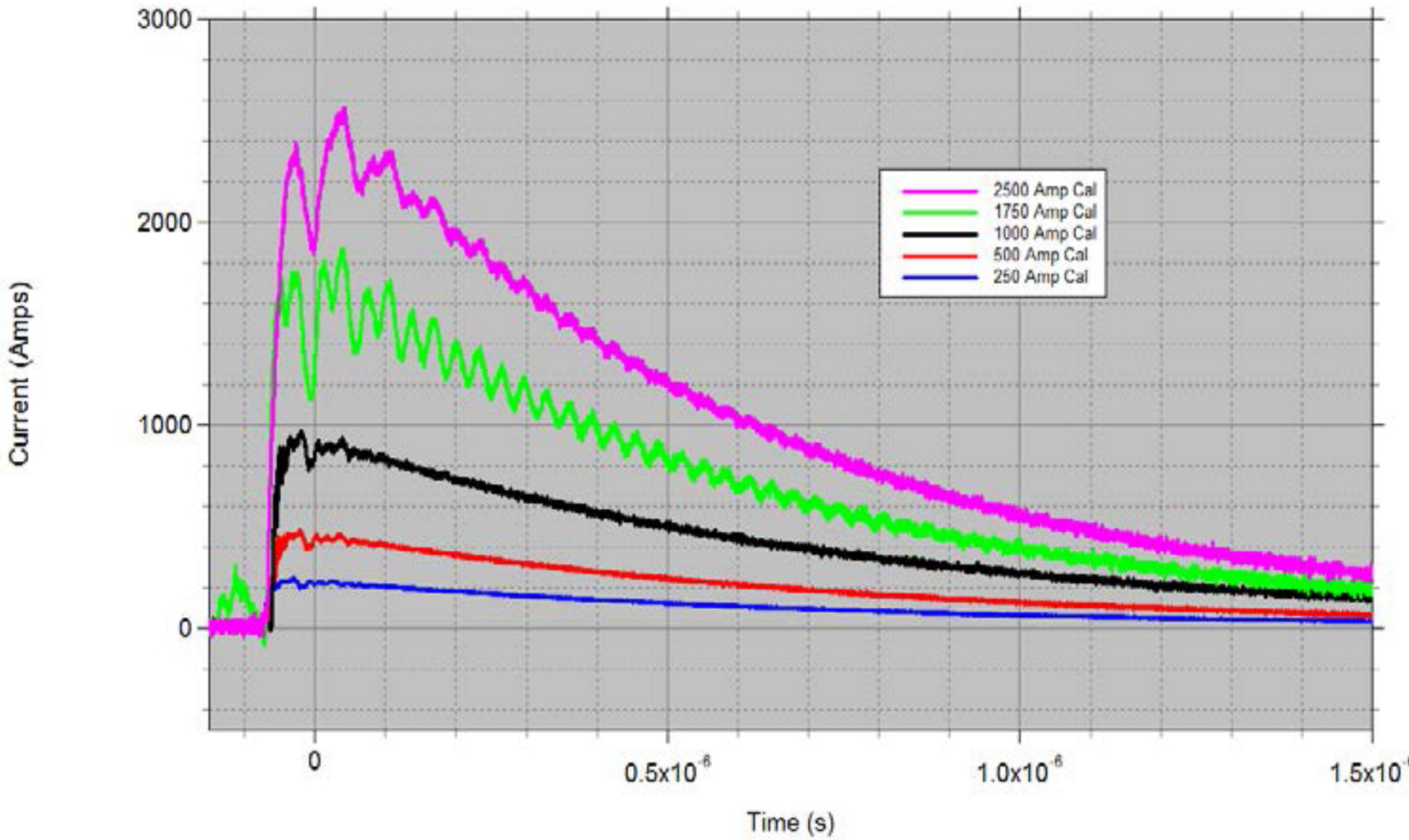




- HEMP Filters tested at independent test lab per MIL-STD-188-125 to ensure it's protection performance compliance.
- Testing the facility after HEMP filter is installed to ensure compliance to MIL-STD-188-125 with overall electrical installations.

Protection Against EMP/HEMP

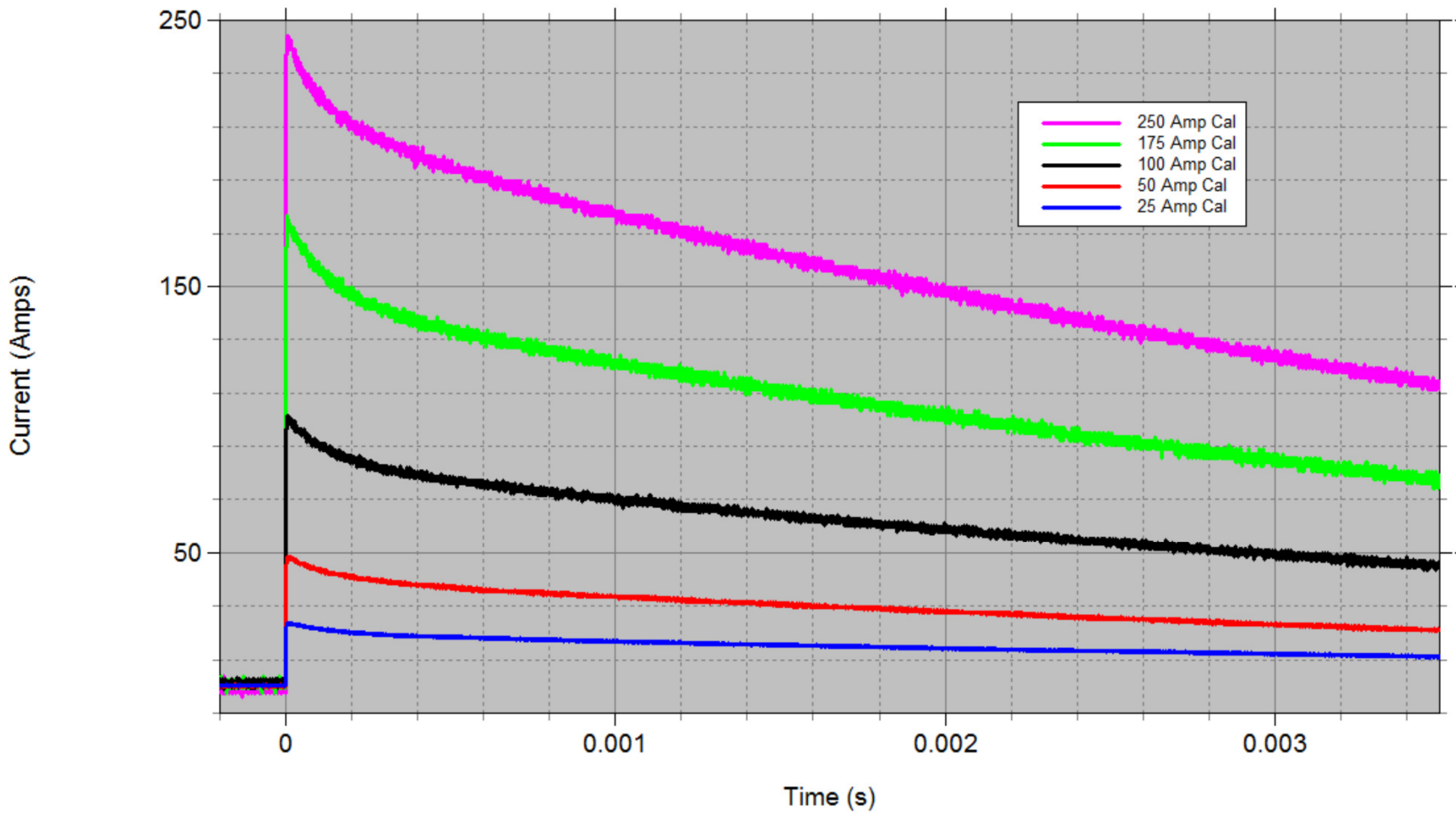
HEMP Filter Testing



E1 Pulser, <20 nSec Rise time, 500-550 nSec FWHM, 250-2500 Amp Drive

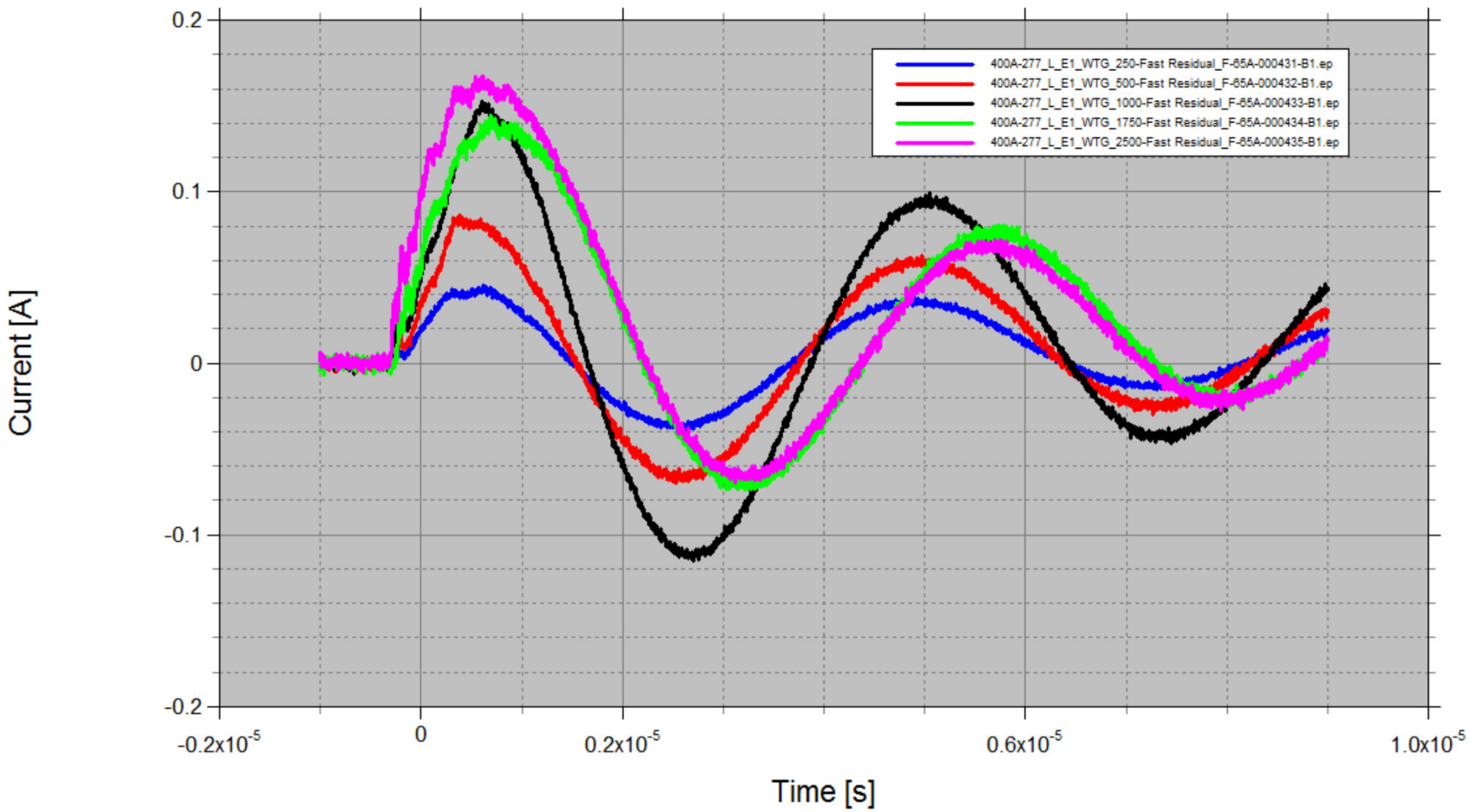
Protection Against EMP/HEMP

HEMP Filter Testing



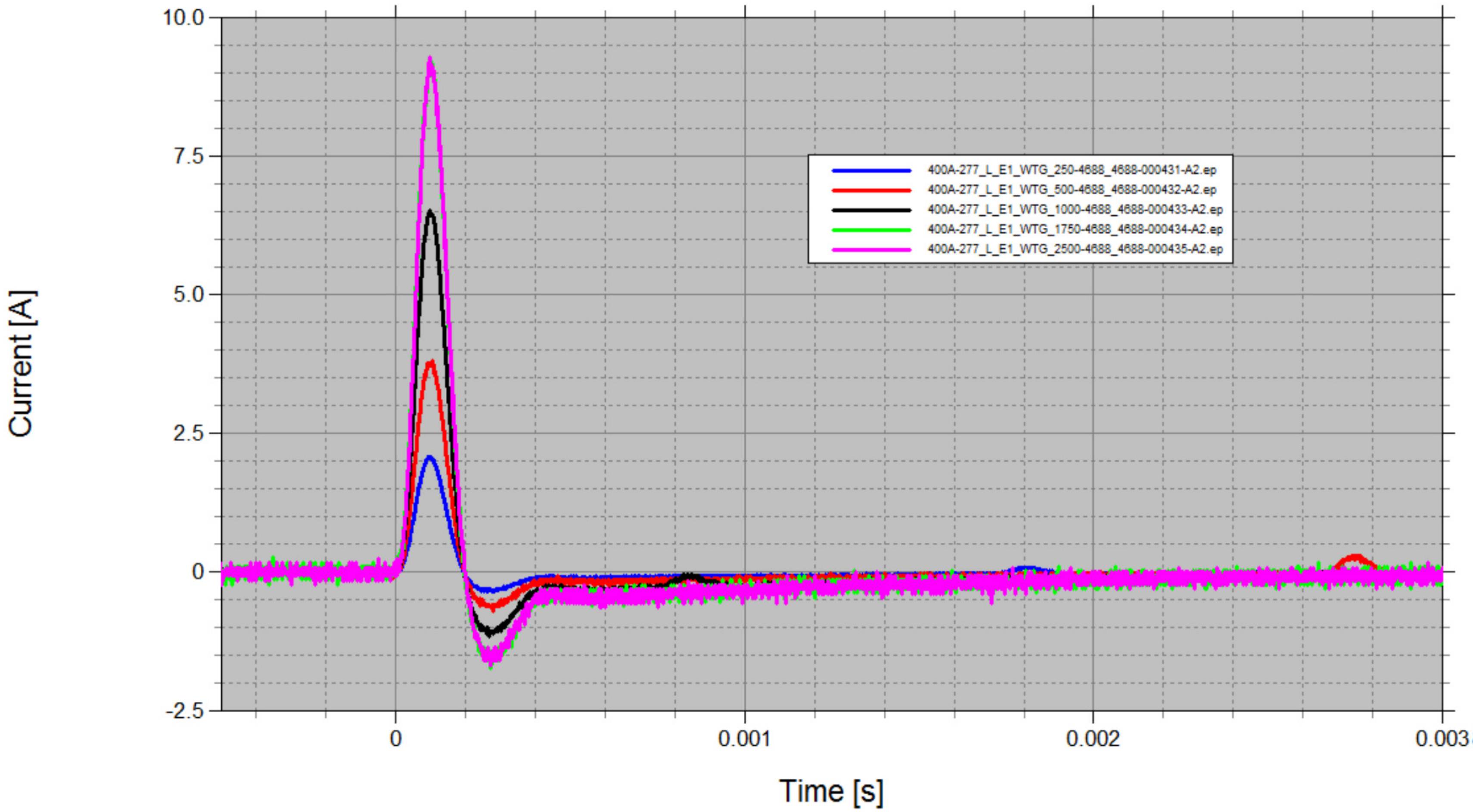
E2 Pulser, <2 uSec Rise Time, 3-5 mSec FWHM, 25-250 Amp Drive

EMP/HEMP Filtering - Fast Residual Performance



100 dB at 14 kHz – 400 Amp 277 VAC

EMI-HEMP Filtering – Slow Residual Performance



100 dB at 14 kHz – 400 Amp 277 VAC

For HEMP Filtering needs contact us

Rafik Stepanian / Anand Awasthi

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