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Electromagnetic Mitigation

Transtector | PolyPhaser

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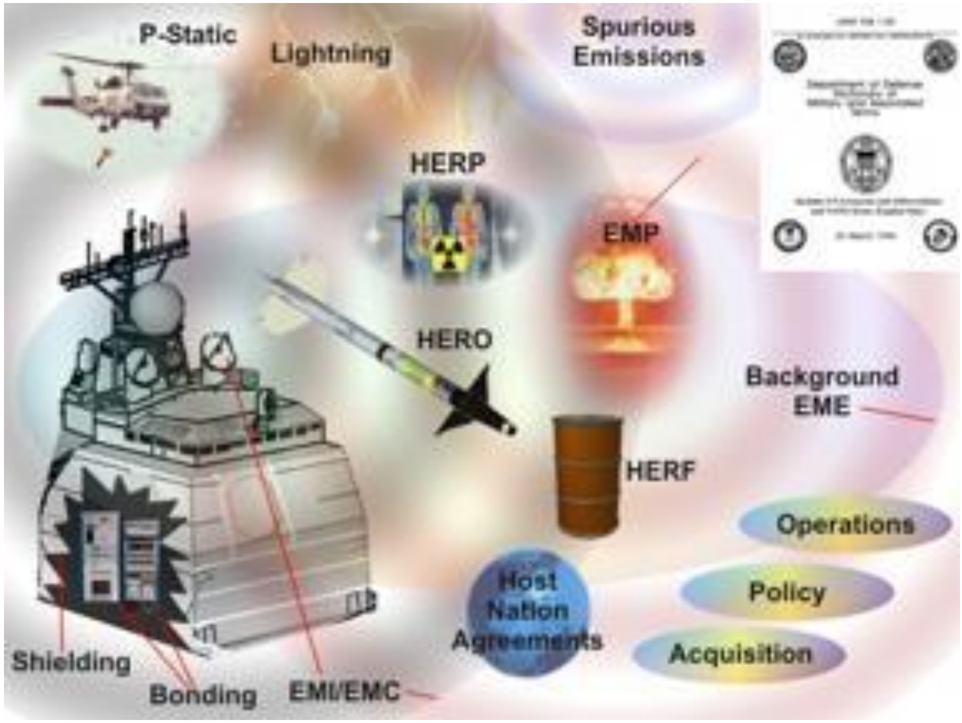
Electromagnetic Effects (E3)

1. EMC Analysis
2. Electromagnetic Compatibility (EMC)
3. Electromagnetic Interference (EMI)
4. Electromagnetic Pulse (EMP)
5. Electromagnetic Vulnerability (EMV)
6. Lightning
7. Radiation Hazards (RADHAZ)
8. P-static
9. Electrostatic Discharge (ESD)
10. Radio Frequency Identification (RFID)
11. Ultra-Wideband (UWB)



Filtering and Suppression

Surge Protection – Surge, Lightning & Transients

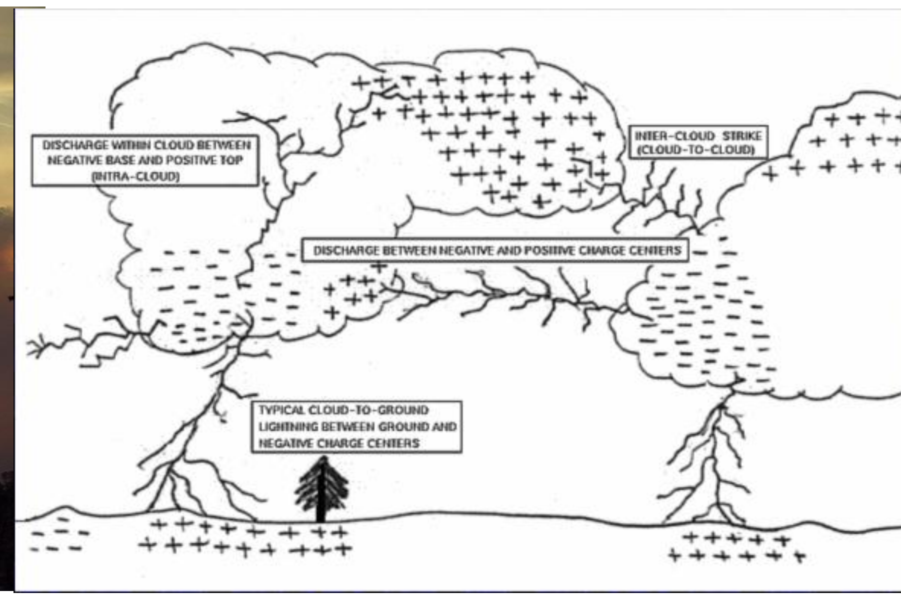
EMI Filters – Radiated or conducted Electromagnetic Interference or Noise

EMP Filters – Electromagnetic Pulse from nuclear detonation ground or atmosphere, Man-made weapons, or Solar Flares.

Surges

Lightning – Mother nature is about 8% of all transients. Transients can reach up to 100kA in energy, but most common is under 30kA.

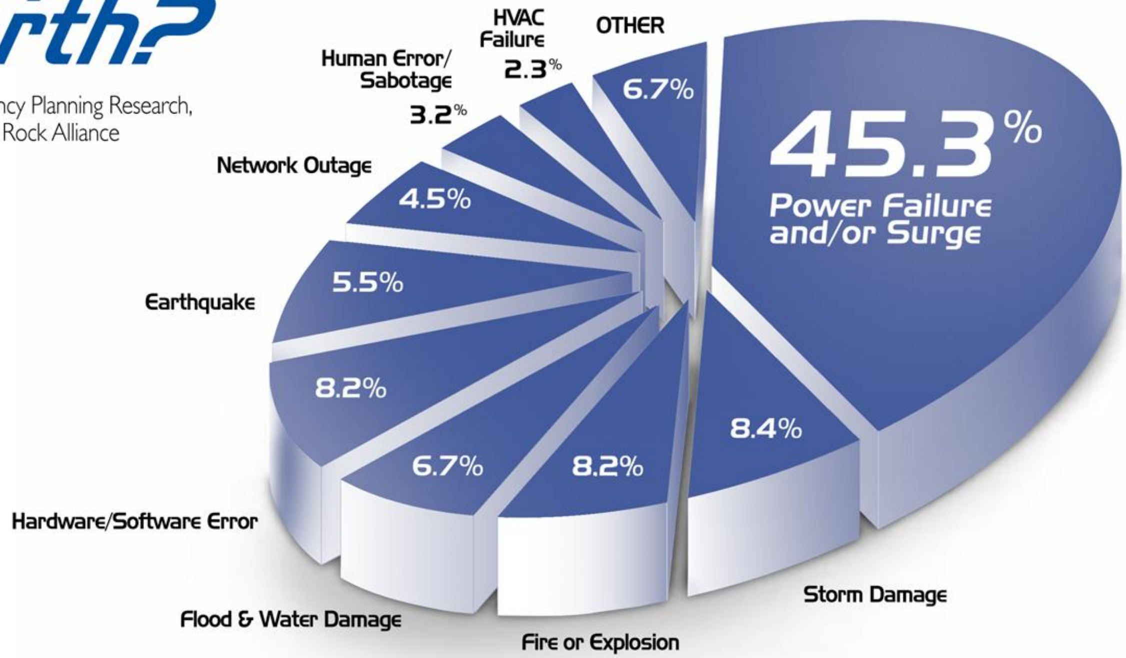
Surges –Man-made events from switching equipment, motors or utility are some examples of equipment that generate surges. Switching equipment located on the load side like motors, AC units, generators, switch mode power supplies and almost anything that turns on or off generates a transient. These events account for the remaining 92% of transients with 12% generated by the utilities and the remaining 80% take place internal on load side equipment.



How Much Is Your Uptime Worth?

SOURCE: Contingency Planning Research, a Division of Eagle Rock Alliance

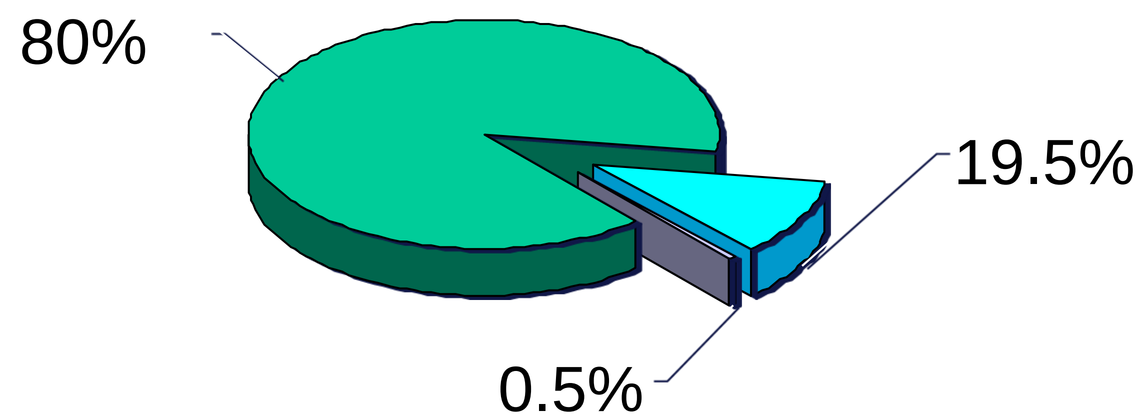
According to an IBM study, VOLTAGE TRANSIENTS represent almost 90% of all power line disturbances



Power Problems – the single largest cause of data loss

Transient Occurrence Rate

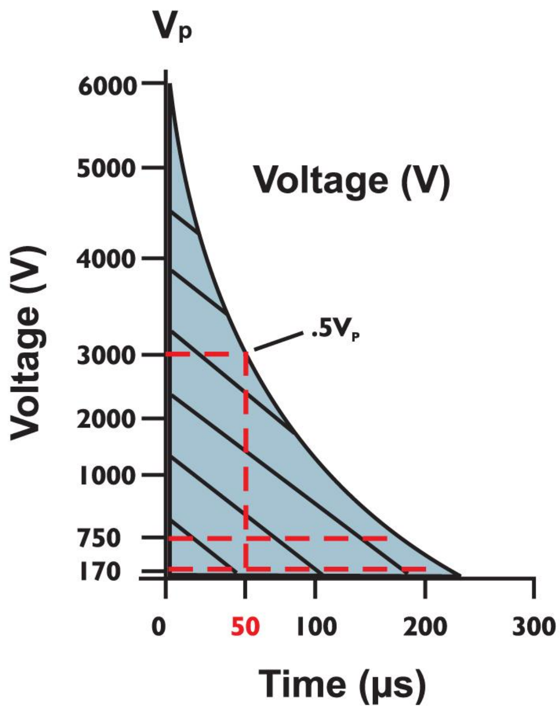
- Transients
- Undervoltages, Harmonics, & Overvoltages
- Voltage Outages

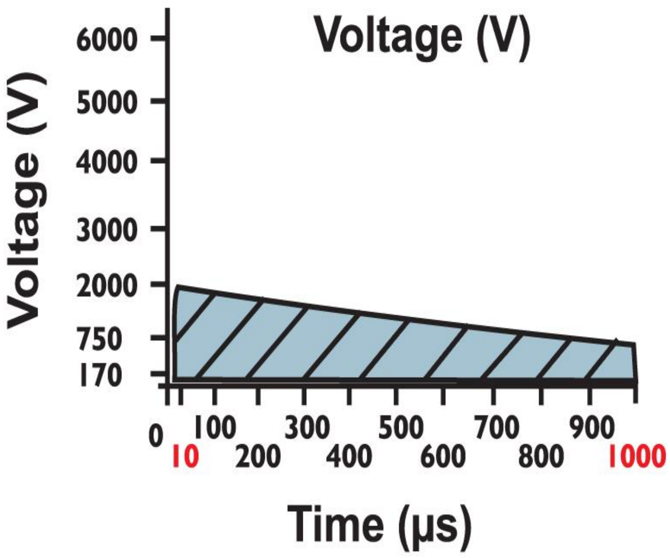


What is a Transient?

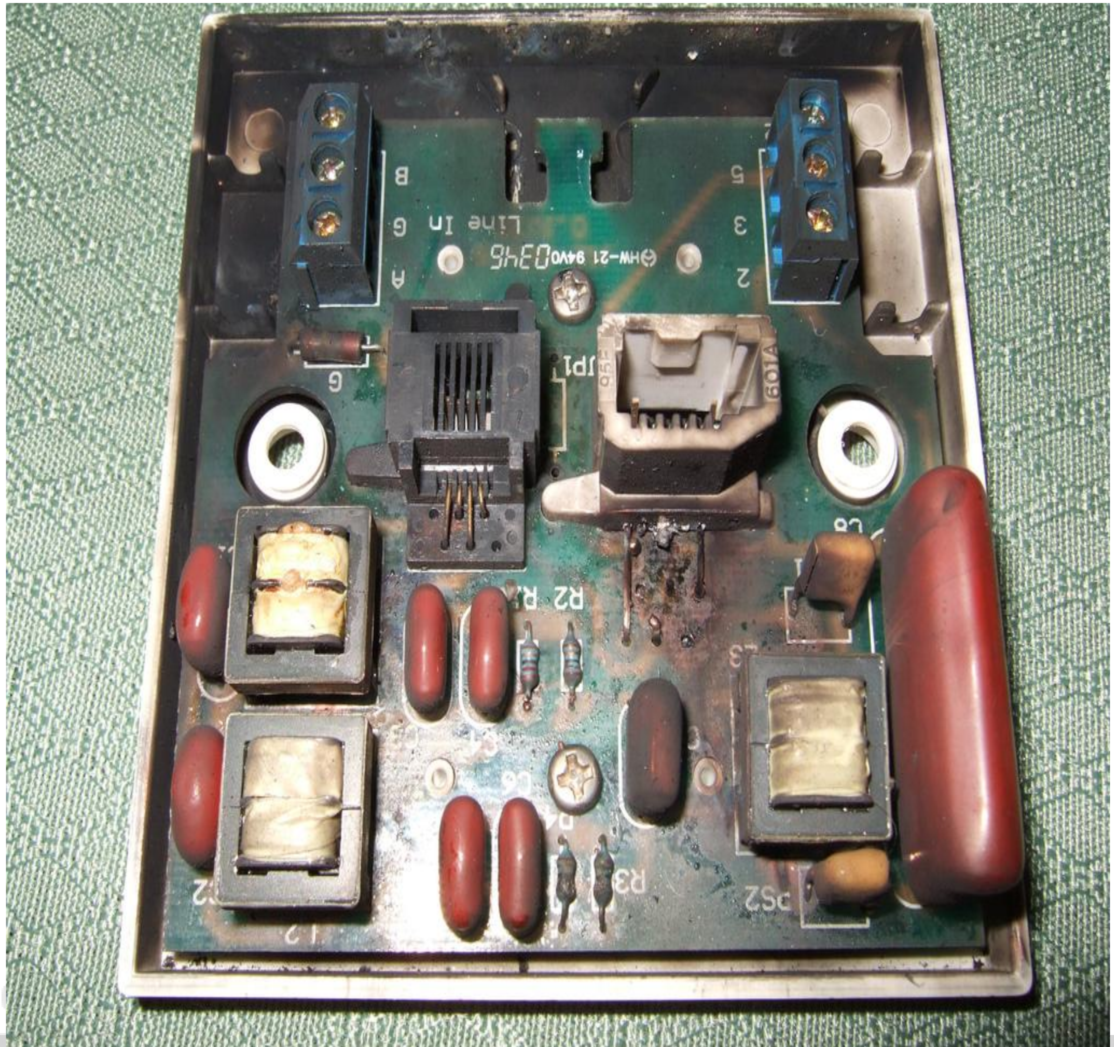
- High frequency events that range from 5 kHz to 100 kHz, can reach the GHz level.
- Short duration in microsecond (Fast rise time)
- Most common transients are under 30kA and can exceed over 100kA.

Surge waveforms 8x20 and 10x1000





Transient Damaged



EMI

- EMI sometimes seems to be the general catch-all term. In fact, it is a generic term for unwanted interference energies conducted as currents or radiated as electromagnetic fields. An EMI source can be any device that transmits, distributes, processes, or utilizes any form of electrical energy where some aspect of its operation generates conducted or radiated signals that can cause equipment performance degradation or failure.

- Every tool or instrument that uses electricity generates associated electromagnetic fields. Voltage causes electric fields and currents cause magnetic fields. It is normal to expect presence of electromagnetic fields in any environment. Not all electromagnetic fields are a problem. Wireless communication is possible solely due to electromagnetic fields, for instance. Electromagnetic fields generate voltages and currents in any conductive object just like they do in mobile phone, radio, or TV antennas. Similarly, electromagnetic fields generate voltages and currents in electric circuits of process equipment, which act just like an antenna.

- When these induced voltages and currents reach the level that can cause undesirable operation of equipment, it is called EMI, or electromagnetic interference. EMI can manifest itself in the following forms:
    - Outright equipment lock-up
    - Tools do things they weren't supposed to do
    - Software errors
    - Erratic response
    - Parametric errors
    - Sensor misreading
    - Component damage
    - Test Equipment having to be recalculated
- All of that causes equipment downtime, loss of productivity and product defects.

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EMP Source

EMP (Electromagnetic Pulse)

- EMP from a nuclear explosion high above the atmosphere.
  - HEMP / NEMP (High Altitude EMP) -A nuclear bomb detonated hundreds of kilometers above the Earth's surface is known as a high-altitude electromagnetic pulse (HEMP) device.
  - Operation Starfish Prime (1962) Johnston Islands in the Pacific

- EMP from a nuclear explosion on the ground
  - Surface Region EMP (SREMP)

- EMP generated by man-made weapons
  - Briefcase Bomb
  - Flux Compression Bomb
  - High Power Microwave (HPM)
  - Directed Energy Weapons (DEW)

- EMP from a solar storm
  - A solar storm that produces an E3 pulse could be even more dangerous to the power grid than a nuclear EMP due to the longer duration of the event that would give transformers more time to overheat to destruction. The risk of large scale failure due to solar storms is especially great in the northern United States and Canada.
  - March 1989 (Quebec) – Solar flare takes down Quebec utility.

- EMP for Outer Space
  - System Generated EMP (SGEMP)
    - Applies to Satellites (X-Ray)

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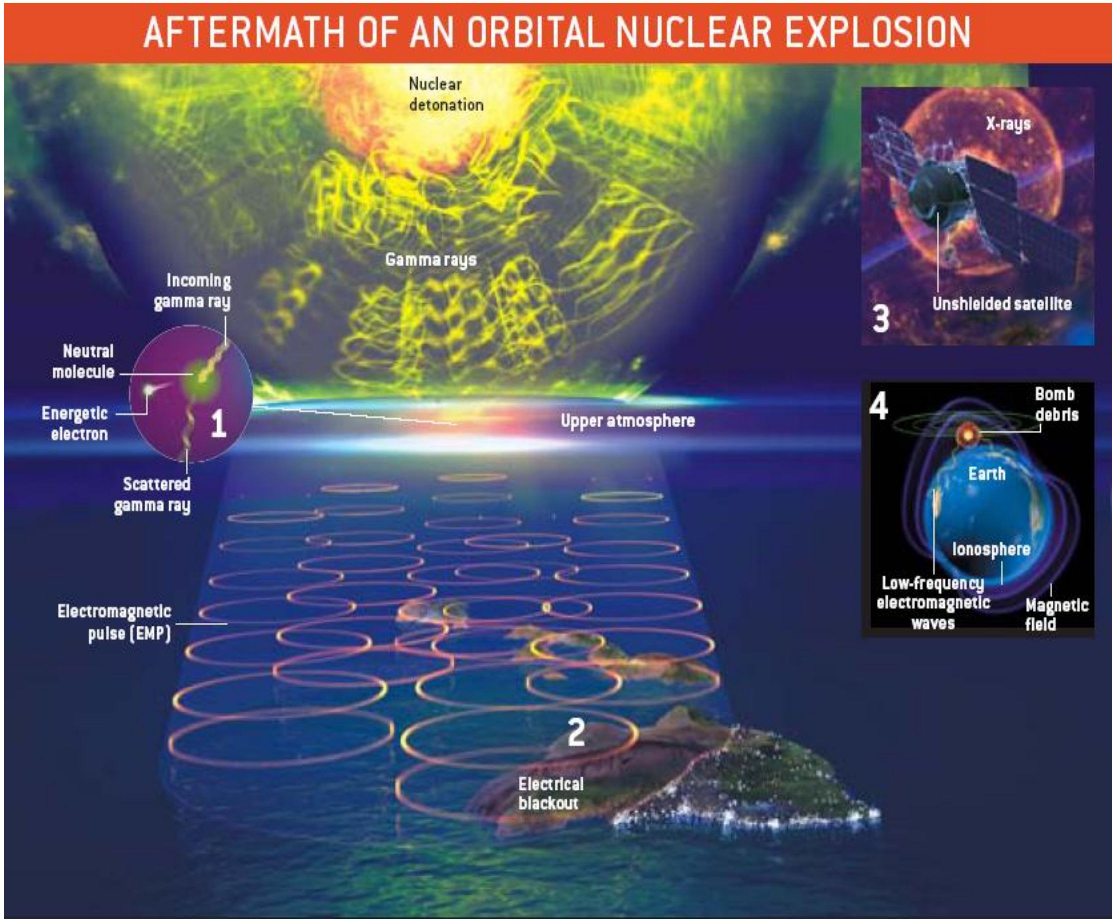
Operation Starfish Prime - EMP



On July 9, 1962, a high-altitude nuclear test named *Starfish Prime* was conducted by the United States military above Johnston Island in the Pacific Ocean. Its unexpected electromagnetic pulse (EMP) effects caused disruptions in electrical systems and equipment in Honolulu 700 miles away. The EMP shut down long-distance telephone calls and disabled three satellites in low earth orbit. It was later learned a total of seven satellites were damaged by knocking out their solar arrays or electronics.

Operation Starfish - EMP

In physics, **Compton scattering** is a type of scattering that X-rays and gamma rays undergo in matter. The inelastic scattering of photons in matter results in a decrease in energy (increase in wavelength) of an X-ray or gamma ray photon, called the **Compton effect**. Part of the energy of the X/gamma ray is transferred to a scattering electron, which recoils and is ejected from its atom, and the rest of the energy is taken by the scattered, "degraded" photon.

Inverse Compton scattering also exists, where the photon gains energy (decreasing in wavelength) upon interaction with matter. Since the wavelength of the scattered light is different from the incident radiation, Compton scattering is an example of inelastic scattering, but the origin of the effect can be considered as an elastic collision between a photon and an electron. The amount the wavelength changes by is called the **Compton shift**. Although nuclear compton scattering exists[1], Compton scattering usually refers to the interaction involving only the electrons of an atom. The Compton effect was observed by Arthur Holly Compton in 1923 at Washington University in St. Louis and further verified by his graduate student Y. H. Woo in the years following. Compton earned the 1927 Nobel Prize in Physics for the discovery.

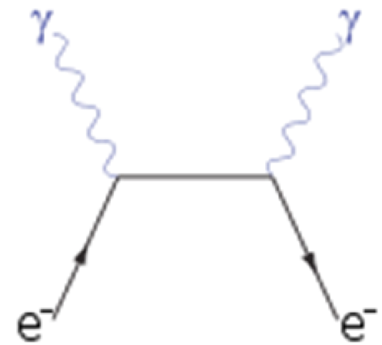
The effect is important because it demonstrates that light cannot be explained purely as a wave phenomenon. Thomson scattering, the classical theory of an electromagnetic wave scattered by charged particles, cannot explain low intensity shifts in wavelength (Classically, light of sufficient intensity for the electric field to accelerate a charged particle to a relativistic speed will cause radiation-pressure recoil and an associated Doppler shift of the scattered light[2], but the effect would become arbitrarily small at sufficiently low light intensities regardless of wavelength.) Light must behave as if it consists of particles in order to explain the low-intensity Compton scattering. Compton's experiment convinced physicists that light can behave as a stream of particle-like objects (quanta) whose energy is proportional to the frequency.

The interaction between electrons and high energy photons (comparable to the rest energy of the electron, 511 keV) results in the electron being given part of the energy (making it recoil), and a photon containing the remaining energy being emitted in a different direction from the original, so that the overall momentum of the system is conserved. If the photon still has enough energy left, the process may be repeated. In this scenario, the electron is treated as free or loosely bound. Experimental verification of momentum conservation in individual Compton scattering processes by Bothe and Geiger as well as by Compton and Simon has been important in disproving the BKS theory.

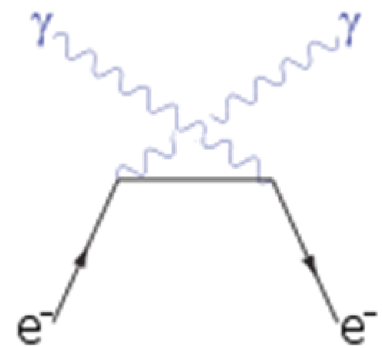
Compton scattering

Feynman diagrams

s-channel



u-channel



Light-matter interaction

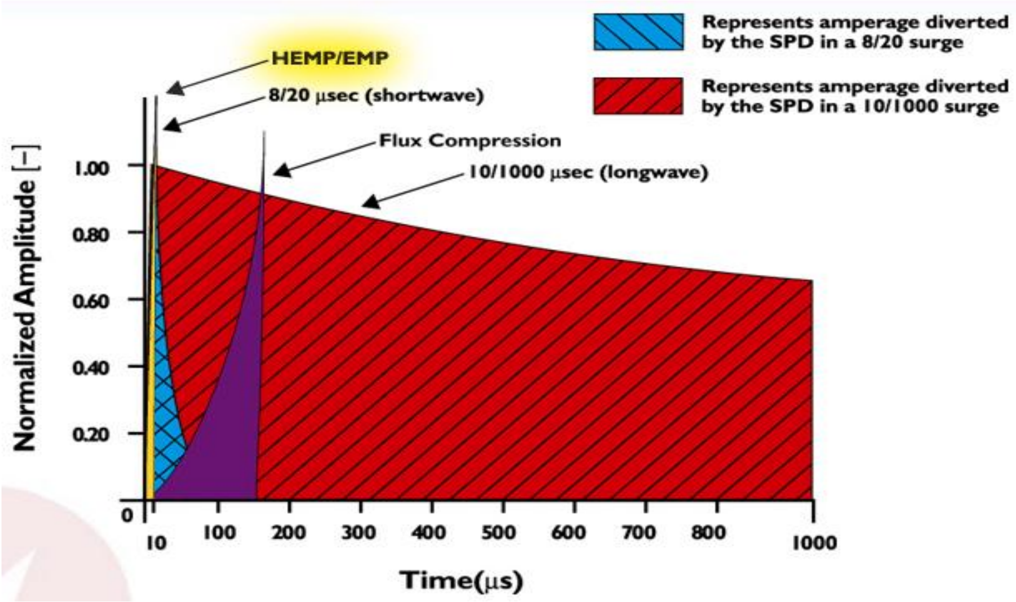
Low energy phenomena Photoelectric effect
Mid-energy phenomena **Compton scattering**
High energy phenomena Pair production

EMP - Pulse and wave shape

- E1 (20/550ns, 300kV, 5kA) fast pulse that must be attenuated down to allow only 10A past the filter into a 10ohm load.

- E2 (1.5us / 3000us, 2500V, 250A) pulses which are much like the IEEE C62.45 8/20us and 10/1000us surge pulses.

- E3 pulse is defined more like a continuous overvoltage condition like the UL1449 Overvoltage Fault Tests and is a much longer pulse. The .2 second rise by 20 second duration E3 pulse is only applicable to exposed connections from long power line and telephone wire lines.



HEMP - Detonated over the US

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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

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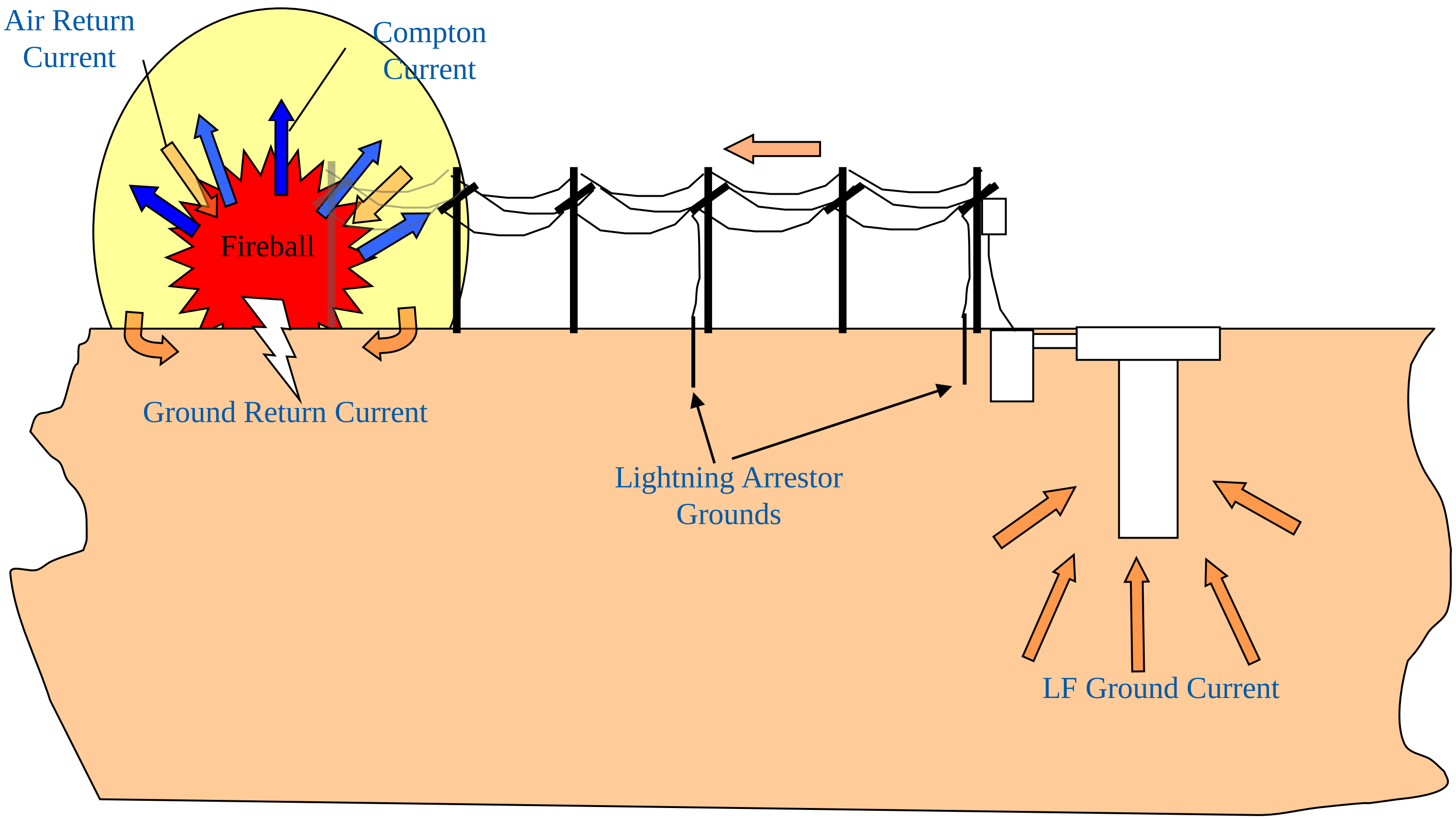
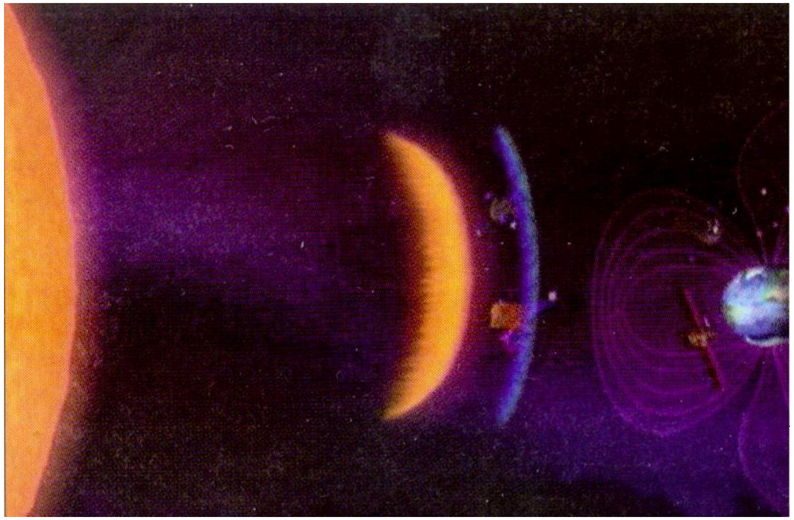
SREMP

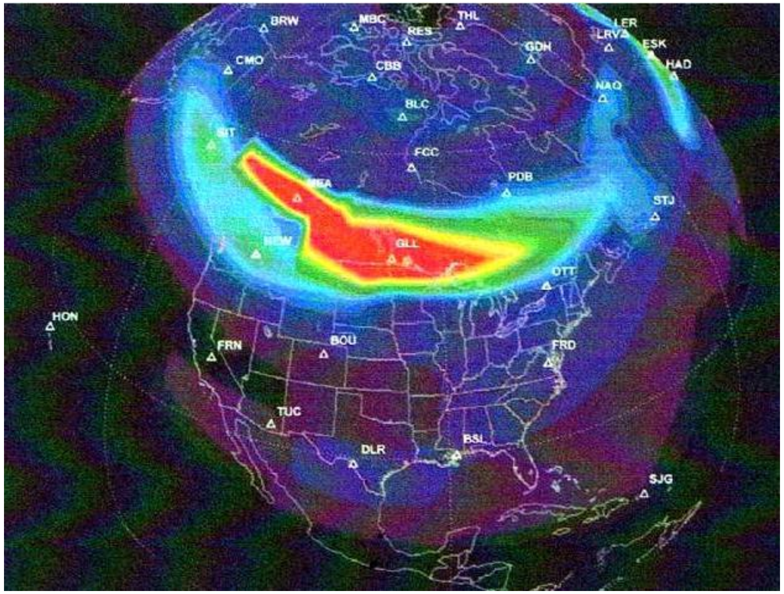


Unclassified

Solar Flares

- According to a report of the National Academy of Sciences, a severe geomagnetic storm could cause economic damage of $1 to $2 trillion (10 to 20 times that of Hurricane Katrina) in the first year, with 4 to 10 years until full recovery.
- One hundred fifty years ago the world's only electrical system – the telegraph network – was destroyed, after British astronomer Richard Carrington observed an unusually **severe solar flare.**
- In a recently published NASA study on severe space weather, scientists concluded that such Carrington-class solar flares occur about once per century. The report warns that a severe flare could occur any time, causing long duration, catastrophic failure of our vital electric infrastructures.
- March 1989 (Quebec) – Solar flare takes down Quebec utility.
  - Knocked out power to 6 million people in 92 seconds.





EMP

"EMP Effects the utility grids, anything that use power, cars, banking industry and any microprocessor based equipment. This would be a complete shut down of our infrastructure."

"Should the electrical power system be lost for any substantial period of time … the consequences are likely to be catastrophic … machines will stop; transportation and communication will be severely restricted; heating, cooling and lighting will cease; food and water supplies will be interrupted; and many people may die"

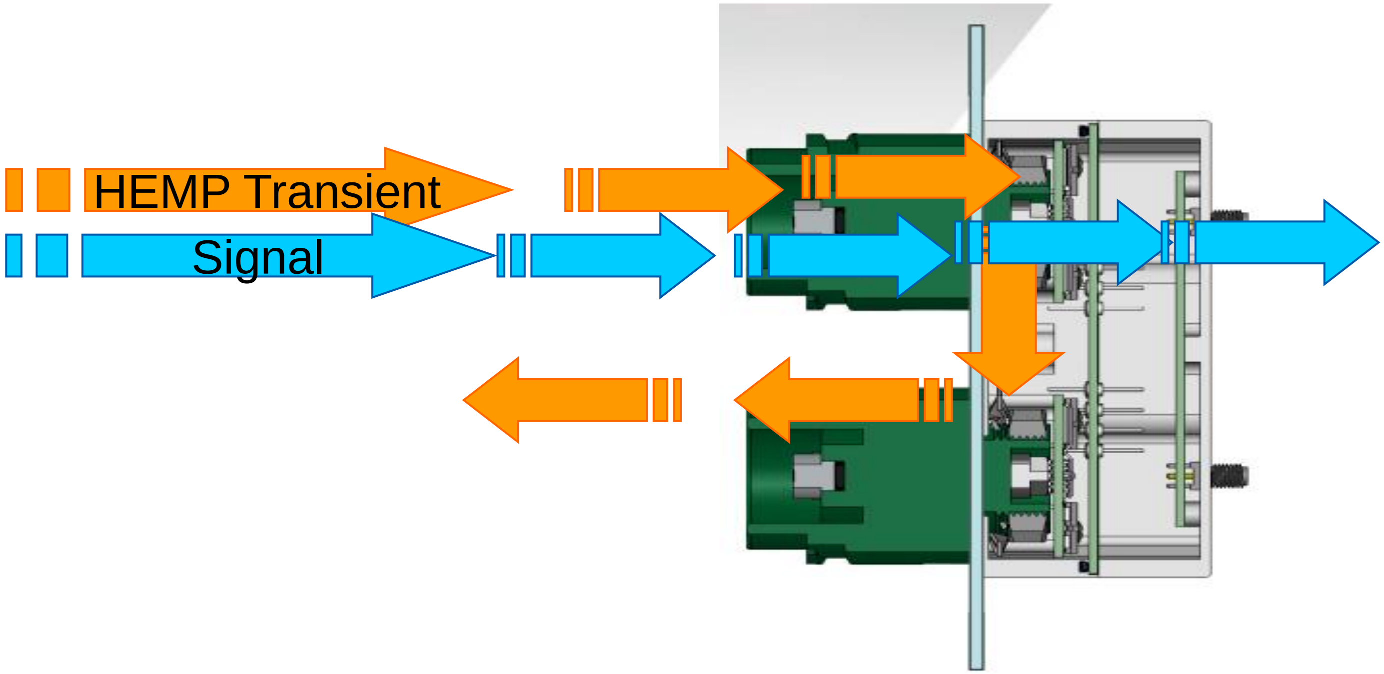
2008 EMP Commission

Hardening Guidelines & Design Considerations

- Threat Environment
  - Applicable Requirements/Flow downs
  - Threat/Coupling Analysis
  - Equipment Immunity Characteristics

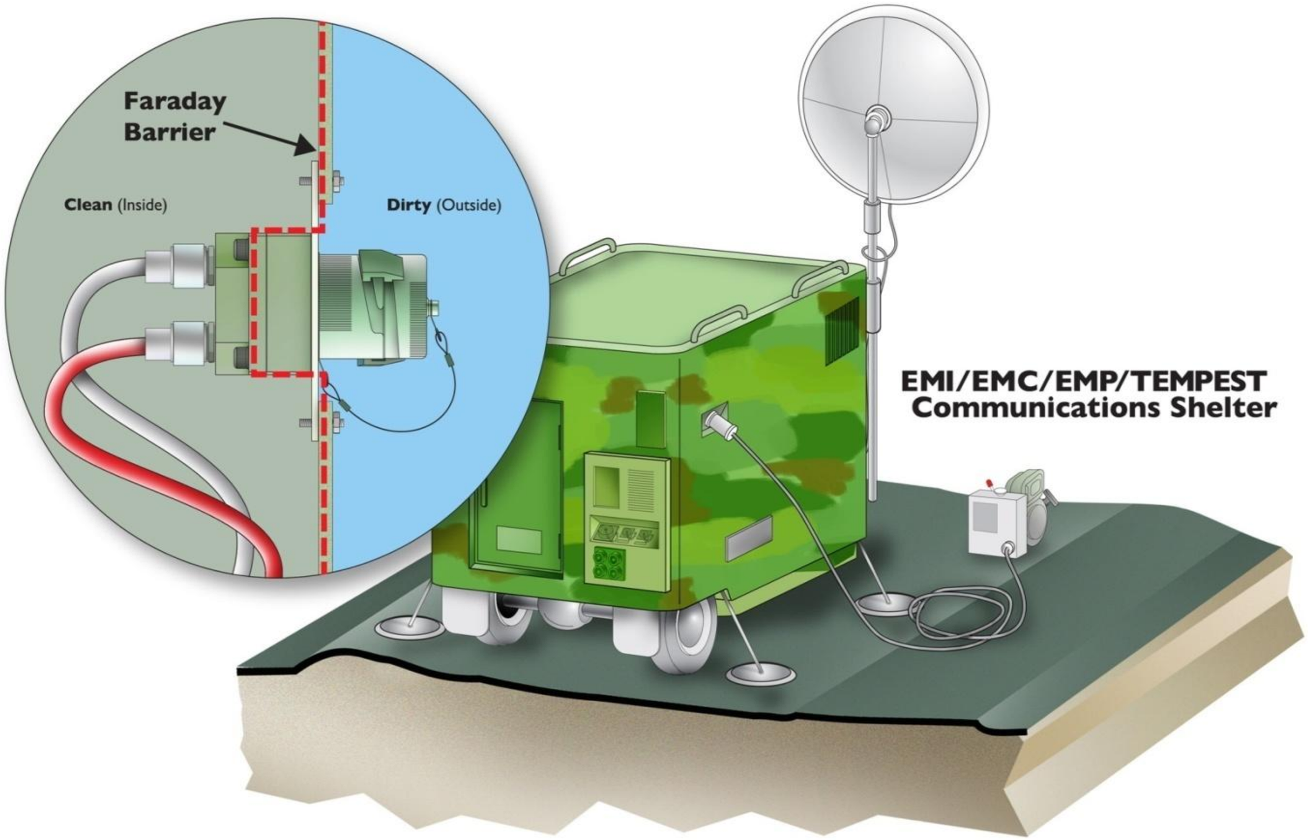
- Hardening Measures
  - Grounding
  - Shielding
  - Filtering
  - Transient Suppression

EMP filtering goal

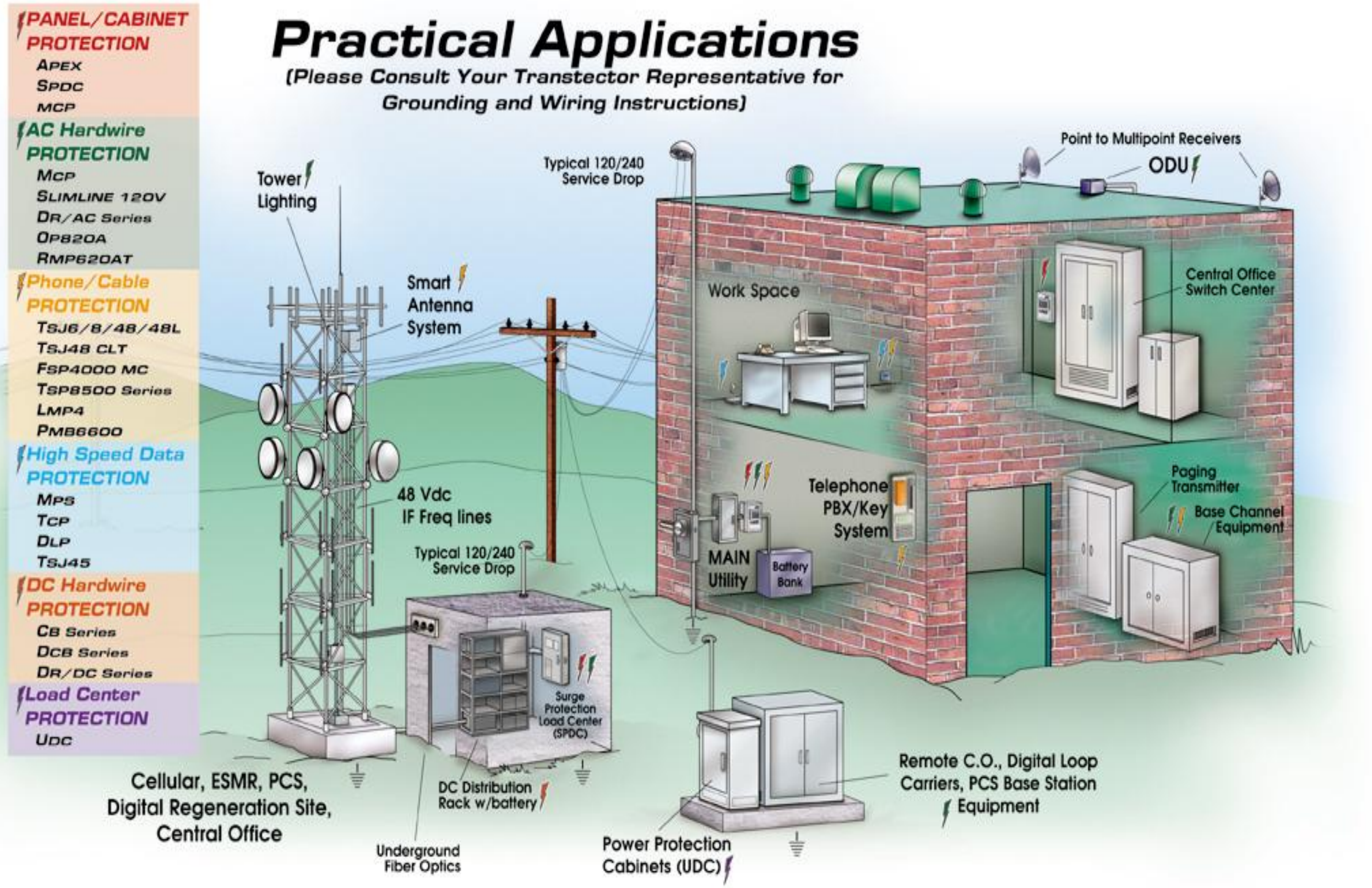


- Grounding – TPM Mounted Directly to Faraday Cage Ground Structure
- Shielding – Mounting Method Maintains Integrity of Faraday Cage
- Filtering – Designed to Minimize Impact on Differential Operating
- Signals while Maximizing Attenuation of Common Mode Threats
- Transient Suppression – GDTs, MOVs & SASDs

EMP Protection



EMP Protection: Transtector Components are a Crucial Element of the System Solution


PANEL/CABINET PROTECTION
APEX
SPDC
MCP
AC Hardwire PROTECTION
MCP
SLIMLINE 120V
DR/AC Series
OP820A
RMP620AT
Phone/Cable PROTECTION
TSJ6/8/48/48L
TSJ48 CLT
FSP4000 MC
TSP8500 Series
LMP4
PMB6600
High Speed Data PROTECTION
MPS
TCP
DLP
TSJ45
DC Hardwire PROTECTION
CB Series
DCB Series
DR/DC Series
Load Center PROTECTION
UDC
Practical Applications
(Please Consult Your Transtector Representative for Grounding and Wiring Instructions)
Tower Lighting
Smart Antenna System
48 Vdc IF Freq lines
Typical 120/240 Service Drop
Typical 120/240 Service Drop
Point to Multipoint Receivers
ODU
Work Space
Central Office Switch Center
Telephone PBX/Key System
MAIN Utility
Battery Bank
Paging Transmitter
Base Channel Equipment
Surge Protection Load Center (SPDC)
Cellular, ESMR, PCS, Digital Regeneration Site, Central Office
DC Distribution Rack w/battery
Underground Fiber Optics
Power Protection Cabinets (UDC)
Remote C.O., Digital Loop Carriers, PCS Base Station Equipment

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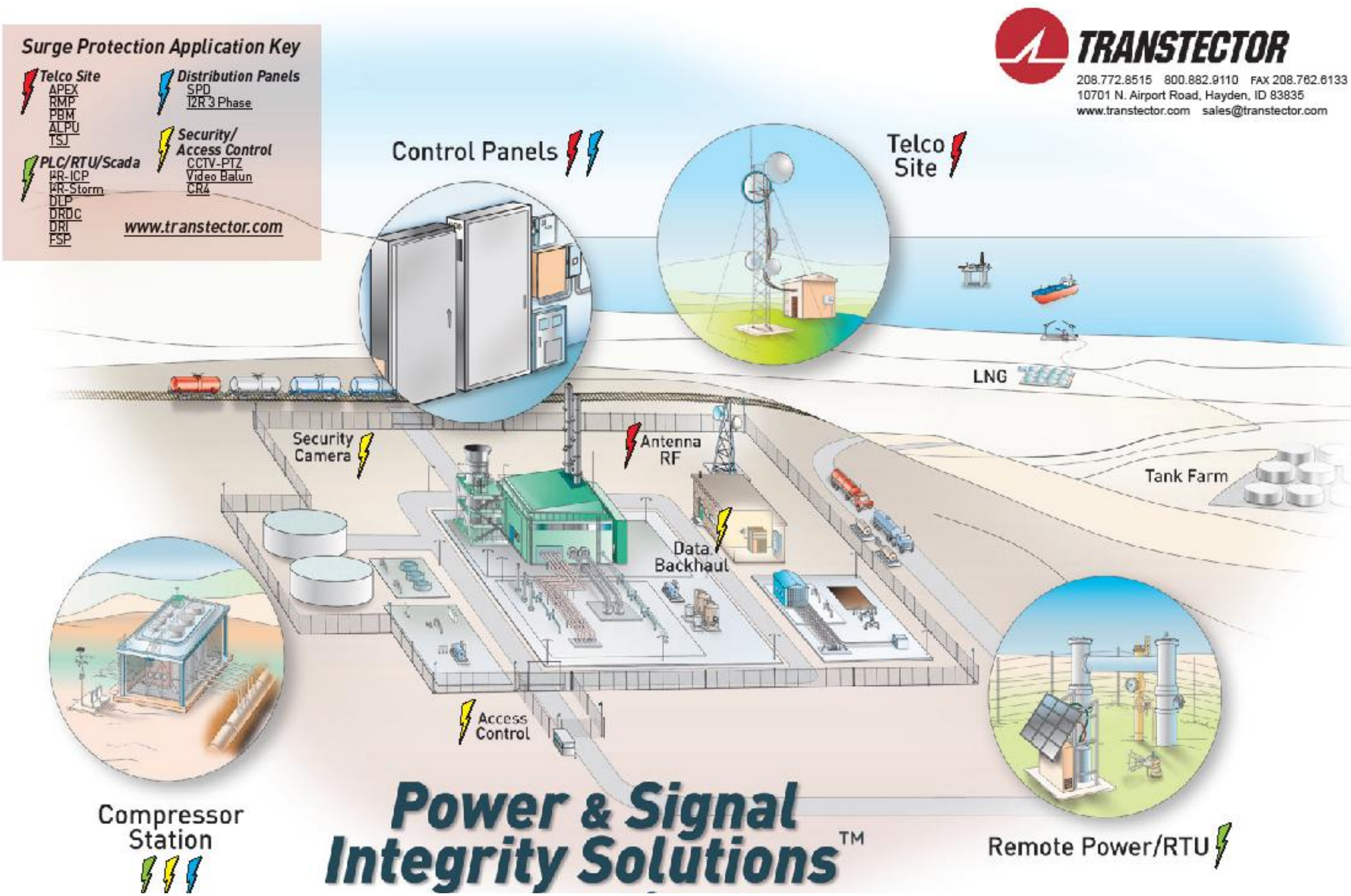

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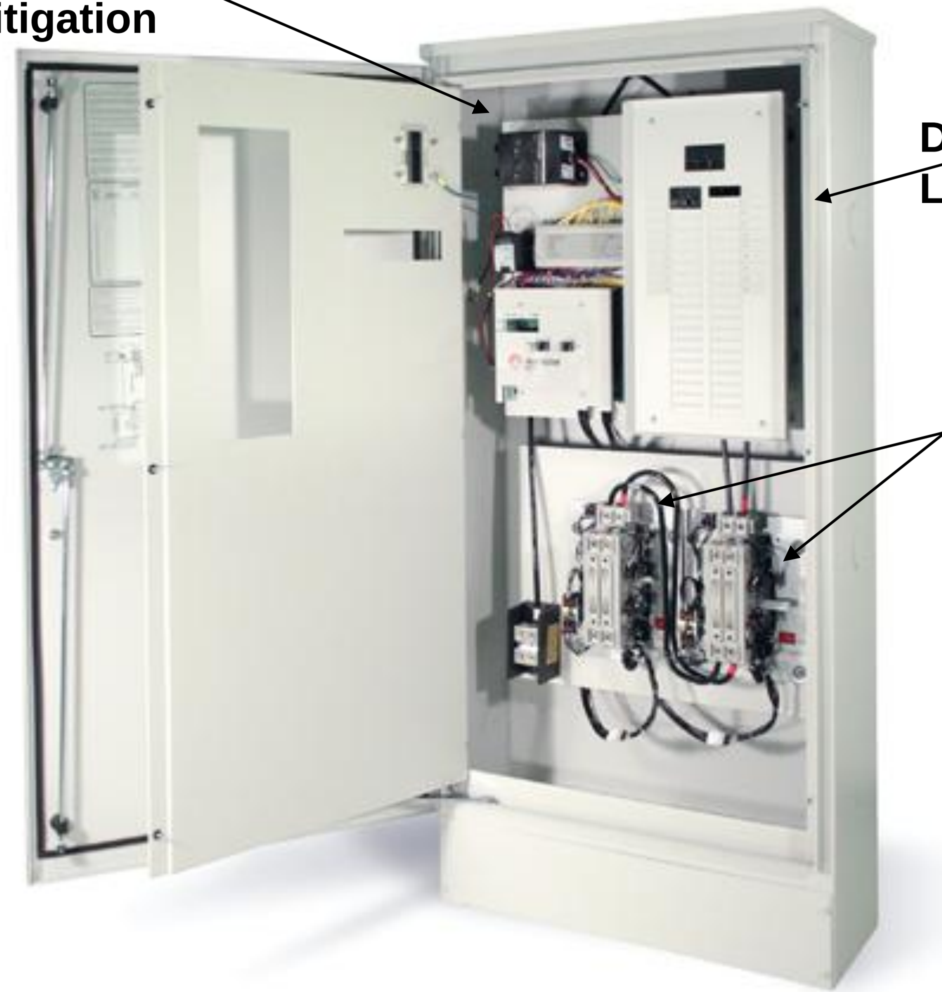

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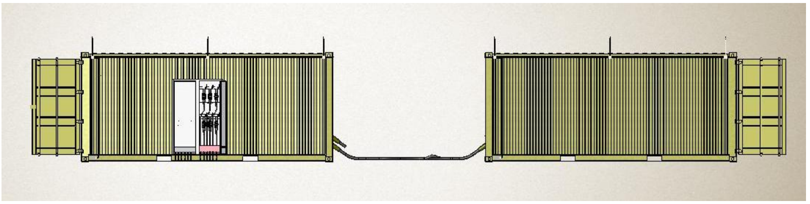
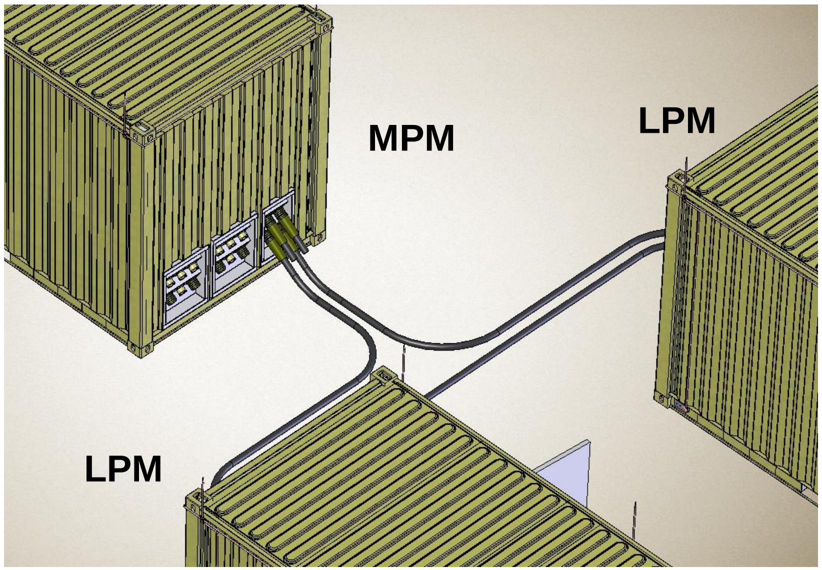
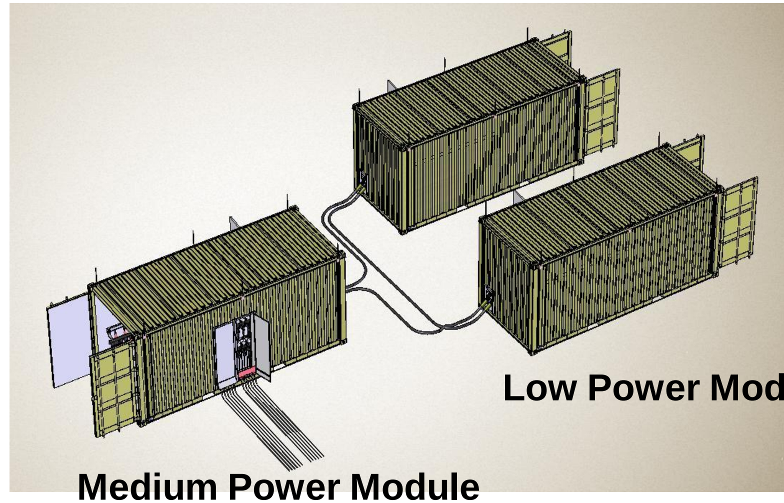
PCDS Physical Layout

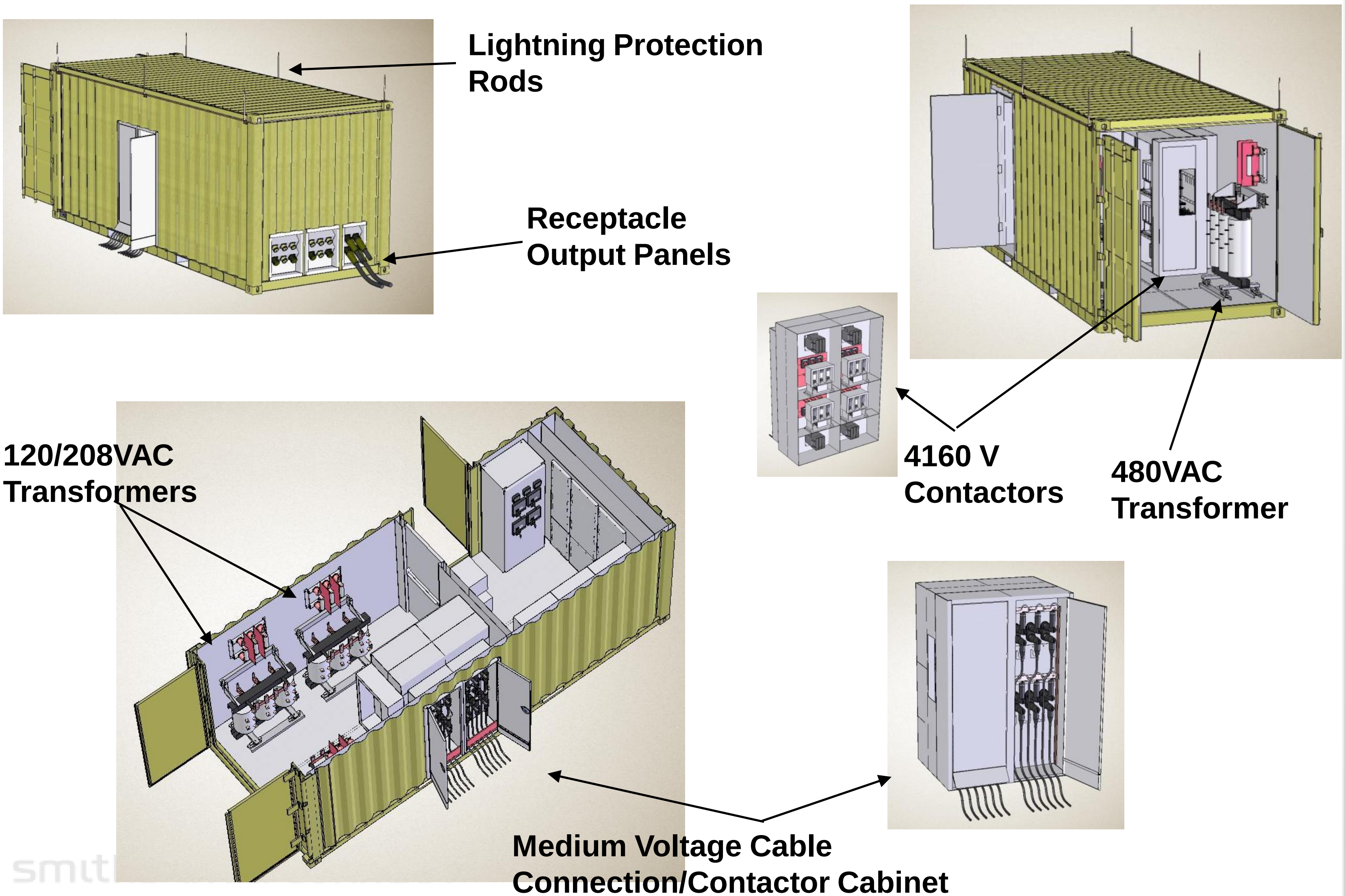


Side view; MPM on left, LPM on right

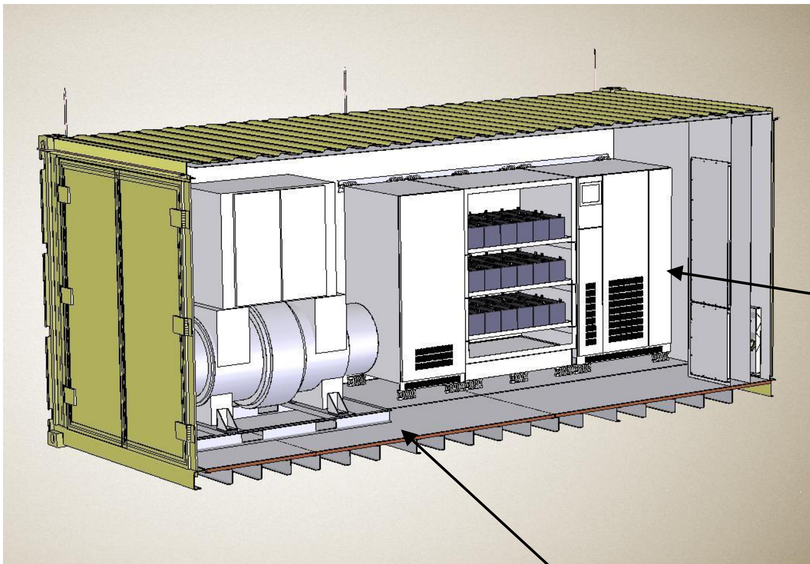


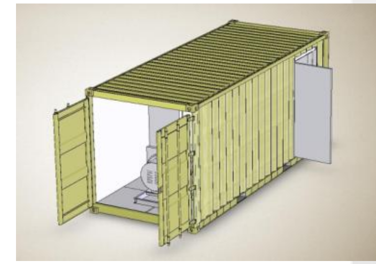


Medium Power Module (MPM)

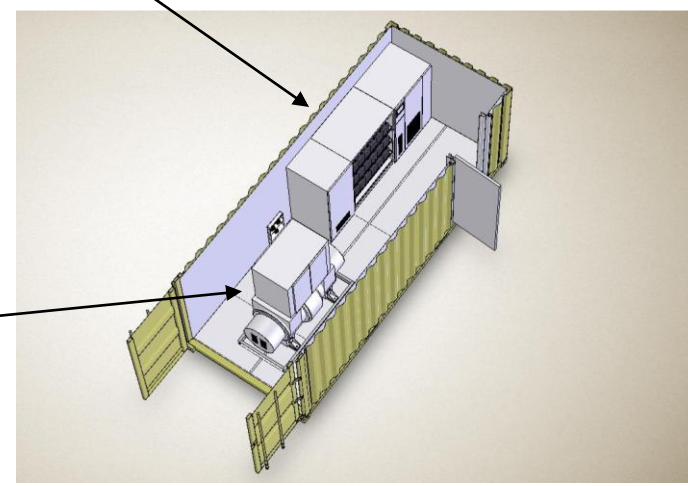


Low Power Module (LPM)

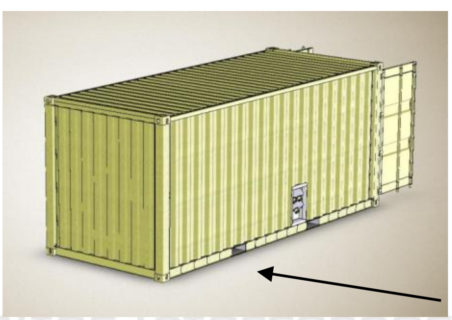




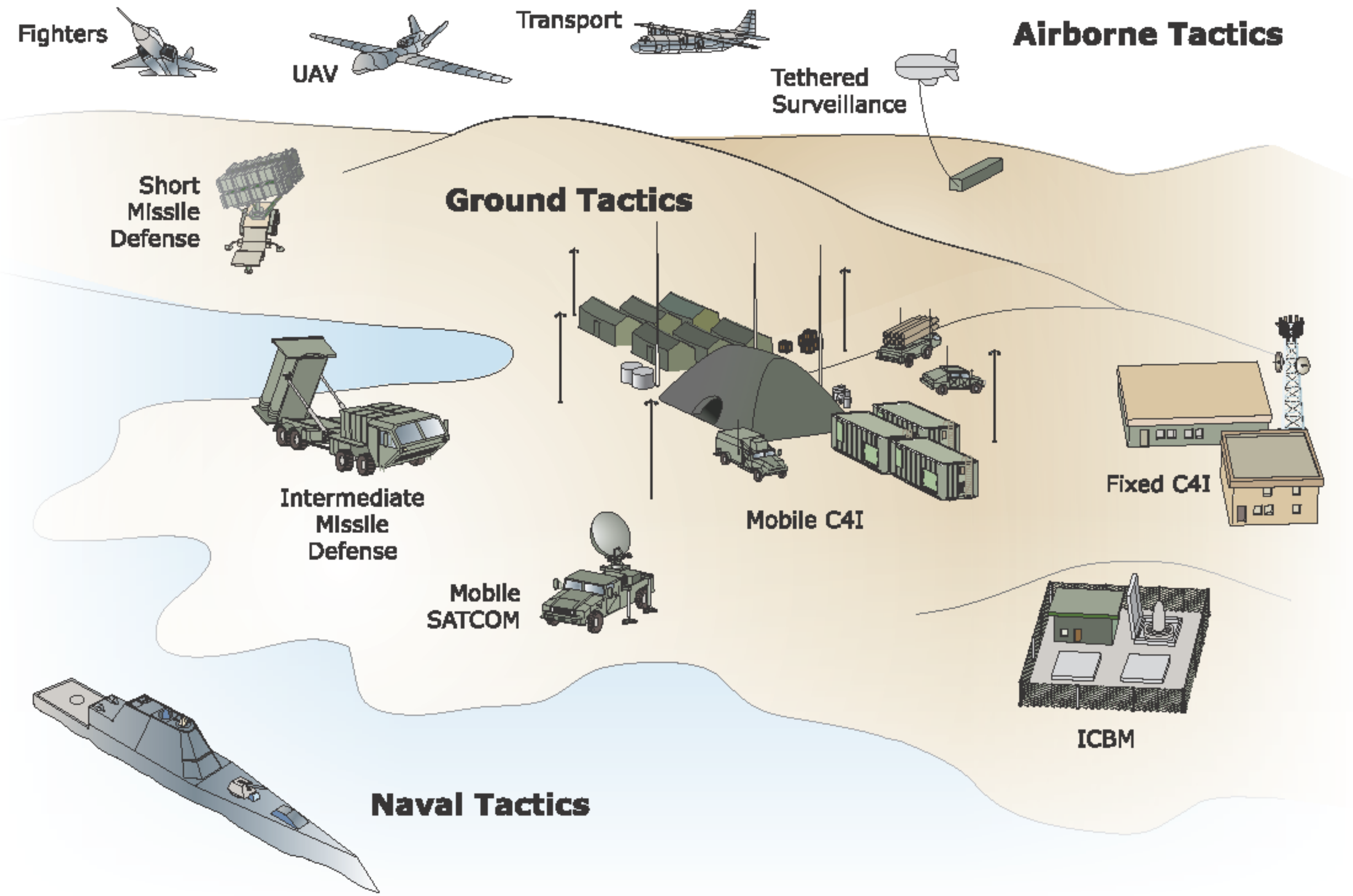
Uninterruptable Power Supply (UPS)



Frequency Generator 400Hz

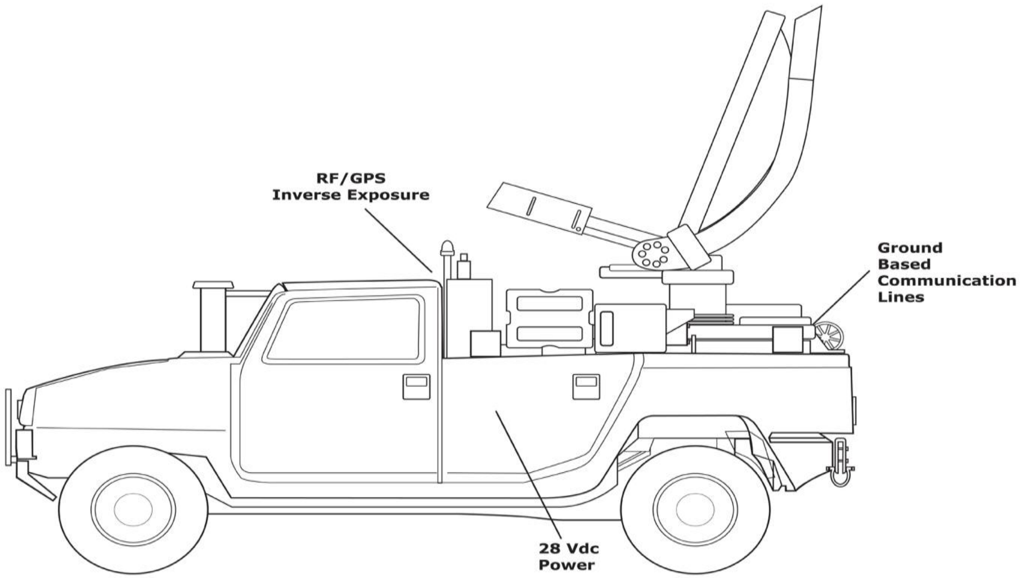


Receptacle Output Panels


Fighters
UAV
Transport
Tethered Surveillance
Airborne Tactics
Short Missile Defense
Ground Tactics
Intermediate Missile Defense
Mobile C4I
Fixed C4I
Mobile SATCOM
ICBM
Naval Tactics

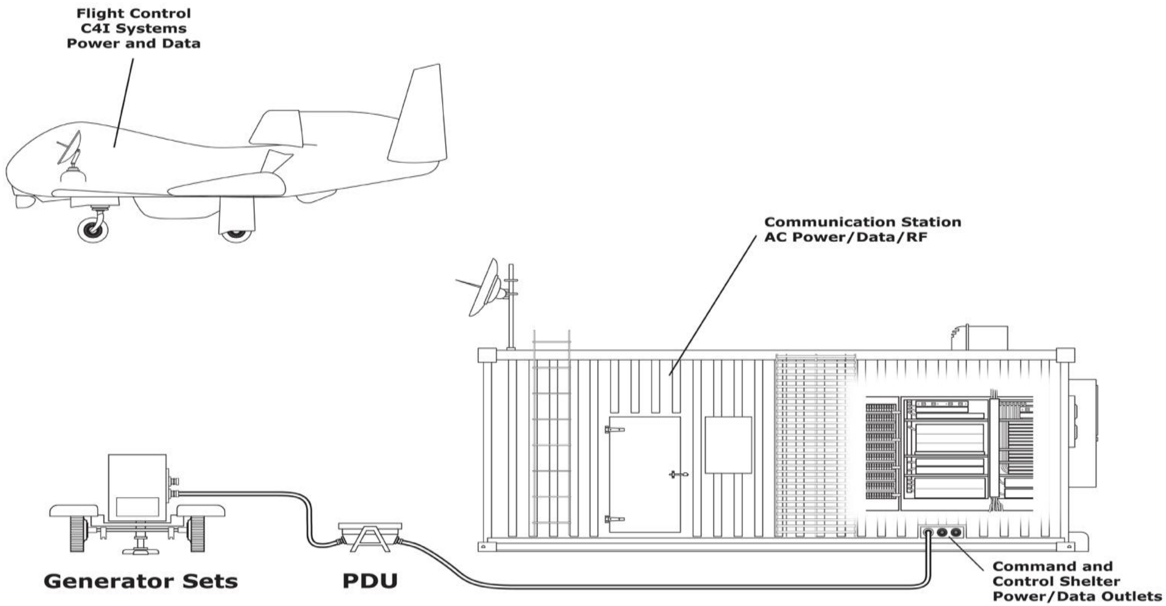
MilAero

Vehicular EMP Protection



MilAero

UAV EMP Protection



STANDARDS

Standards

- MIL-STD-2169B (classified) - 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 (Systems)
- MIL-STD-810F - Shock & Vibe
- RTCA DO-160E - Aircraft EMI & Surge
- UL, NEC, IEC, IEEE, NEMA - Commercial Standards

Mil-STD-188-125
EMP

Mil-STD-188-125

- The 188-125 Family of Standards Define all Aspects of the Construction and Validation of HEMP Hardened C4I Facilities

  - Appendix A – Shielding Effectiveness (SE)

  - Appendix B – Pulse Current Injection (PCI)
    - Early Time HEMP (E1) Waveform – 20/500ns
    - Intermediate Time HEMP (E2) Waveform – 1.5/3000µs
    - Late Time HEMP (E3) Waveform – 1000A for 60s

  Appendix C – Continuous Wave Immersion (CWI)

Qualification and Validation Testing

•Per MIL-STD-188-125-1 appendix A, SE
"These procedures shall be used for shielding effectiveness acceptance testing of the facility HEMP shield and aperture POE protective treatments. The procedures shall also be performed for acceptance of repairs or installations of new POE protective devices after construction acceptance, except that only areas affected by the repair or installation are required to be tested. Shielding effectiveness measurements may also be conducted as part of the verification test program."

A.5.5 Pass/fail criteria.[9] The shielding effectiveness pass/fail criteria are shown as a function of frequency by figure A-5. The facility HEMP shield and aperture POE protective treatments shall be considered satisfactory when both of the following criteria are met:

a. No sequence of measurements occurs at three consecutive frequencies with the measured shielding effectiveness below the minimum requirements curve (figure A-5).

b. No more than 10 percent of the measurements in any decade (10 kHz – 100 kHz, 100 kHz – 1 MHz, 1 MHz – 10 MHz, 10 MHz – 100 MHz, and 100 MHz – 1 GHz) are below the minimum requirements.

[9] When a shielding effectiveness measurement is performed on a test area surface or test point between the barrier exterior and a special protective volume, the pass/fail criteria are as specified in the design of that special protective volume. A measurement in the adjacent protected volume is also required, to demonstrate that the total attenuation through the main barrier and special protective barrier satisfies these pass/fail requirements.

MIL-STD-188-125-1

APPENDIX A

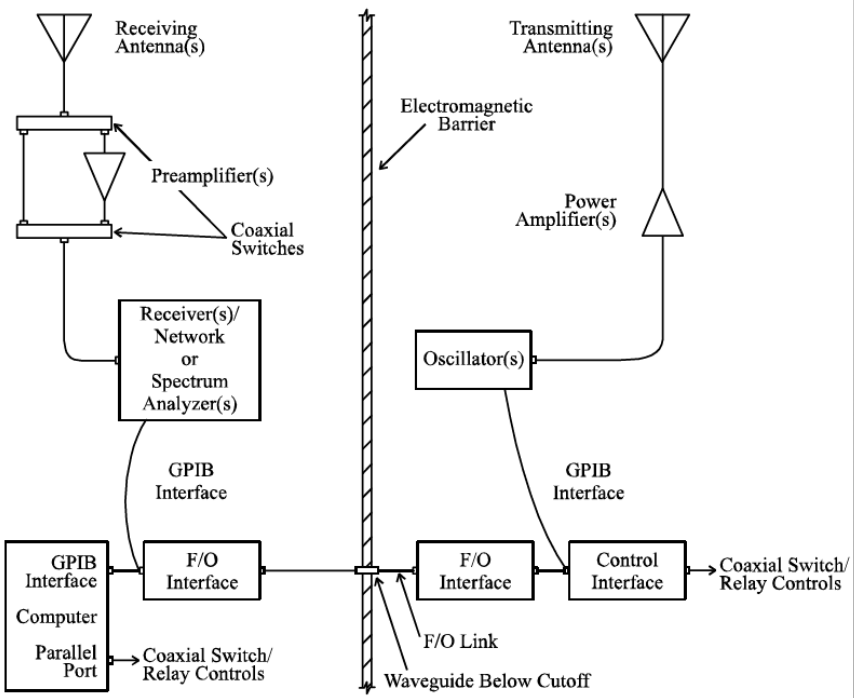


FIGURE A-1. Typical shielding effectiveness instrumentation system.

MIL-STD-188-125 Appendix A, SE

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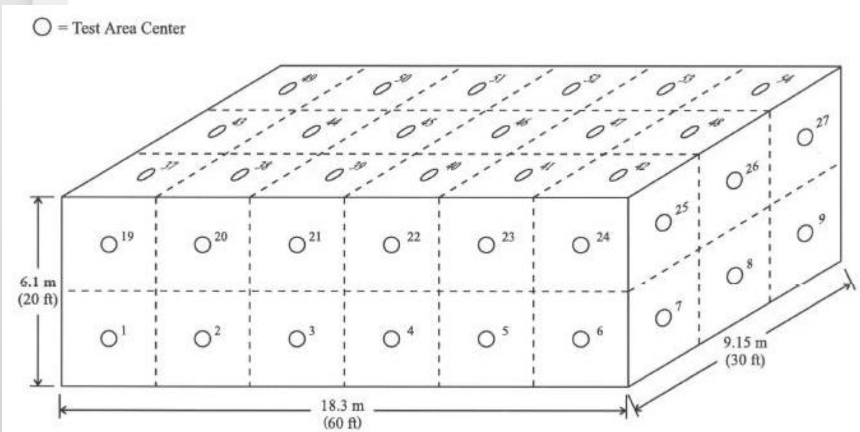
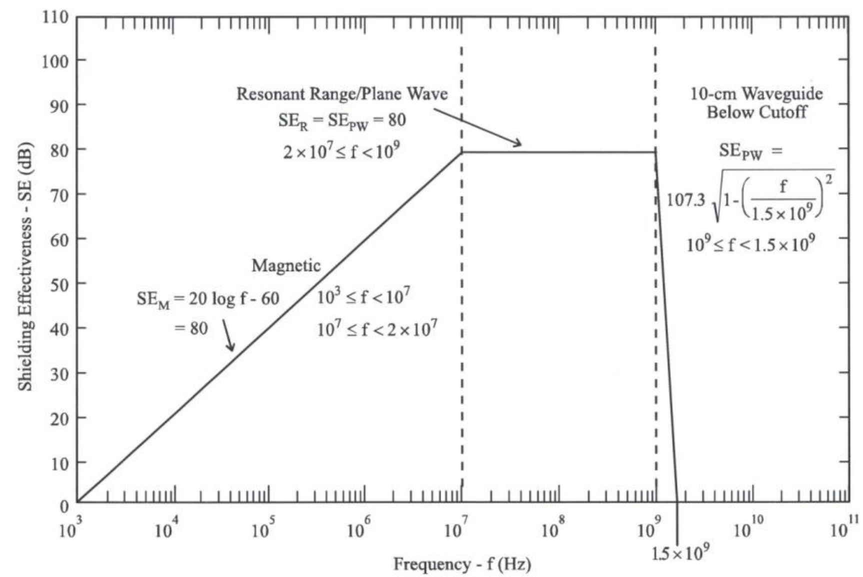
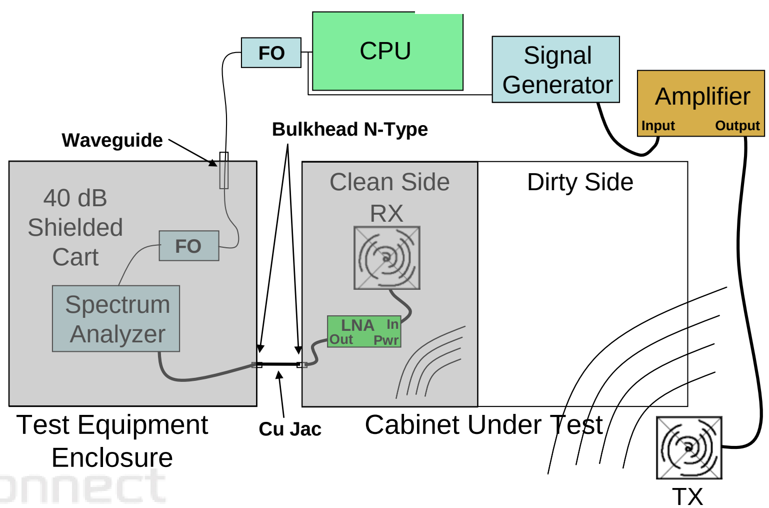


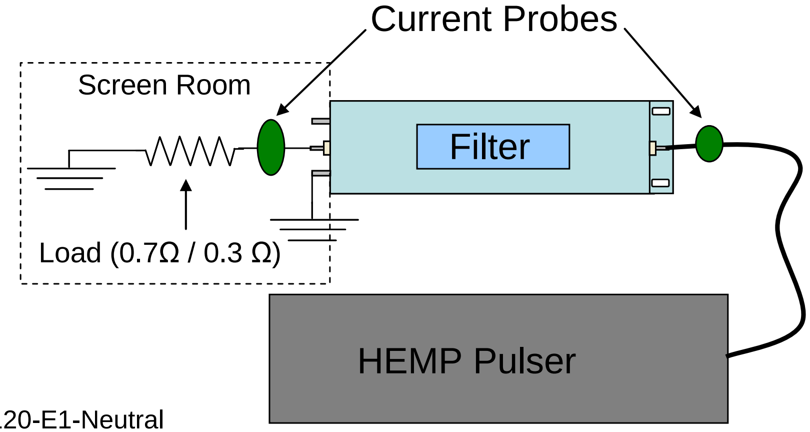


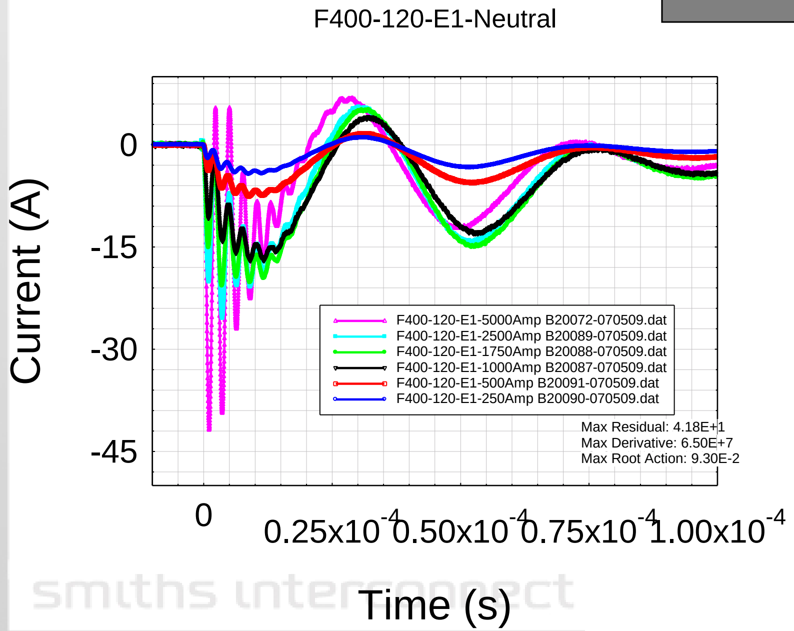


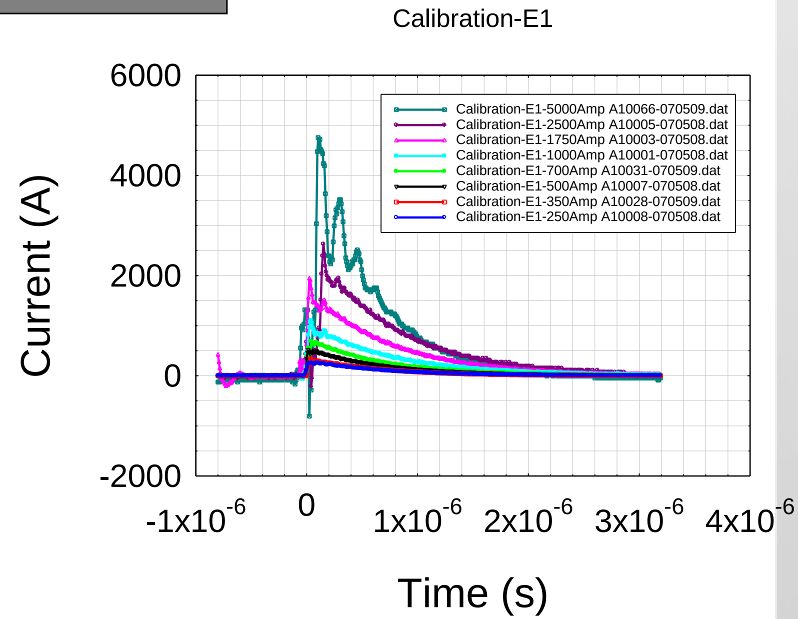
MIL-STD-188-125 Appendix B, PCI Testing

- Early Time HEMP Waveform (E1), 20/500ns
  - 60Ω Generator Impedance
  - Maximum Drive Current (Per Pin) = 2500A
  - Very High Voltage is Required !
  - Pass/Fail Determined by Analysis of Residual Norms Measured Across a Resistive Test Load
    - Peak Current (10A Max for Power, 0.1A Max for Data)
    - Peak Rate of Rise (1E7 A/s)
    - Peak Root Action (1.6E-1 A*s^0.5 for Power, 1.6E-3 A*s^0.5 for Data)

MIL-STD-188-125 Appendix B, PCI (Cont'd)







Qualification and Validation Testing

•Per MIL-STD-188-125-1 appendix B, PCI "These procedures shall be used for acceptance testing after construction of the HEMP protection subsystem and for verification testing of electrical POE protective treatments after the facility is completed and operational."

B.5.5.1 Internal response pass/fail criteria. The POE protective device shall be considered satisfactory when both of the following criteria are met:

a. Norms of the measured internal response waveforms, at all short pulse injection levels, do not exceed the maximum allowable norm values of table B-III for the applicable class of electrical POE.[13] If internal responses measured in the PCI verification test cannot be discriminated from circuit operating and noise signals, the test shall be repeated in a power-off (acceptance) configuration. The pass/fail determination for internal response norms shall then be made using the resulting power-off data.

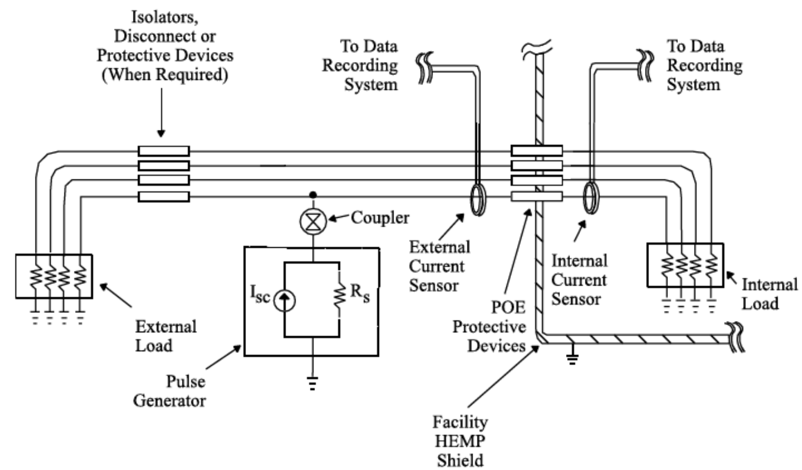
b. Post-test physical inspection of the POE protective device, measurement of surge arrester (if installed) voltage at 1 mA dc current (for a metal oxide varistor) or dc breakdown voltage (for a spark gap), and response data analysis indicate that the device has not been damaged or degraded by the test pulses.

The internal response pass/fail criteria apply for both acceptance and verification testing.

B.5.5.2 Verification test functional pass/fail criteria. Hardening of equipment within the electromagnetic barrier shall be considered satisfactory when both of the following criteria are met:

a. No damage to MCS occurred during the PCI verification testing.

b. No mission-aborting interruption of mission-critical functions or upsets of MCS occurred during the PCI verification testing.[14]



b. Wire-to-ground test configuration.

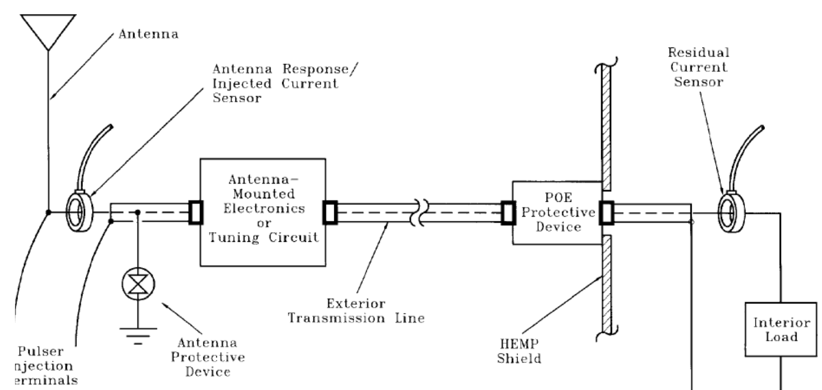


FIGURE B-4. Antenna subsystem configuration for coupling measurements and PCI testing.

protection technology group
POLYPHASER | TRANSTECTOR | DOWIN | LEA | RO ASSOCIATES

MIL-STD-188-125 Appendix B PCI Testing (Cont'd)

HEMP E1 Testing @ SARA Inc. - Colorado Springs

smiths interconnect

Mil-STD- 461
EMI Subsystems

Mil-STD- 461

- MIL-STD-461 Establishes the Interface and Verification Requirements for the EMI Characteristics of Electronic Equipment and Subsystems Procured by the DoD

- Primary Intent of Standard is to Ensure EMC/Interoperability of Subsystems Being Integrated into a System

- Standard is Divided into 4 Categories of Tests
  - Conducted Emissions (CE)
  - Conducted Susceptibility (CS)
  - Radiated Emissions (RE)
  - Radiated Susceptibility (RS)

- Our Products Cannot Guarantee Subsystem Compliance to this Standard, but they can Contribute to the Equipment's Ability to Comply!

Mil-STD- 461

Requirement Description
CE101 Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102 Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106 Conducted Emissions, Antenna Terminal, 10 kHz to 40 GHz
CS101 Conducted Susceptibility, Power Leads, 30 Hz to 150 kHz
CS103 Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104 Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105 Conducted Susceptibility, Antenna Port, Cross-Modulation, 30 Hz to 20 GHz
CS106 Conducted Susceptibility, Transients, Power Leads
CS109 Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz
CS114 Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 200 MHz
CS115 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116 Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10 kHz to 100 MHz
RE101 Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102 Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RE103 Radiated Emissions, Antenna Spurious and Harmonic Outputs, 10 kHz to 40 GHz
RS101 Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS103 Radiated Susceptibility, Electric Field, 2 MHz to 40 GHz
RS105 Radiated Susceptibility, Transient Electromagnetic Field

Mil-STD- 464
EMI System

Mil-STD- 464

- MIL-STD-464 Provides Basic Requirements for Electromagnetic Environmental Effects (E3) Considerations for DoD Systems

- Primary Intent of Standard is to Provide Guidance and Test Methods for Electromagnetic Threats at the System Level

- E3 Definitions that are addressed in the Standard Include:
  - Lightning
  - EMP
  - EMI/EMC
  - HERP/HERO/HERF

- Contribution of Compliance by our Products is Twice Removed at the System Level, Therefore Compliance Analysis must be Qualitative

Ancillary Requirements, Military

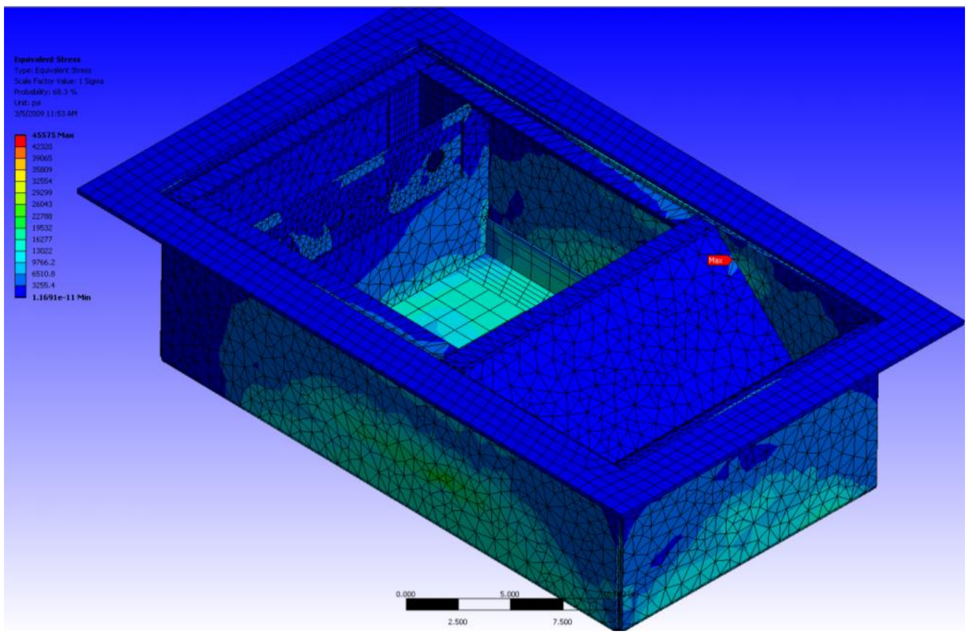
- TEMPEST (Classified)
  - 100dB Insertion Loss 14kHz – 1GHz for AC Power Feeds

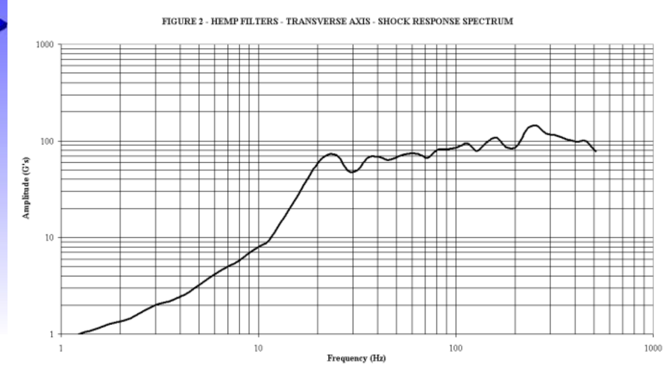
- Power Quality Requirements
  - Voltage Drop, Typically 1% Maximum
  - Shunt Current, Varies by Service Current
  - Harmonic Distortion, Typically 5% THD Maximum

- Environmental Requirements
  - MIL-STD-202 – Component Level
  - MIL-STD-810 – Box Level
  - Operating Temp, Shock, Vibration, Humidity, Salt Fog Vary by Program

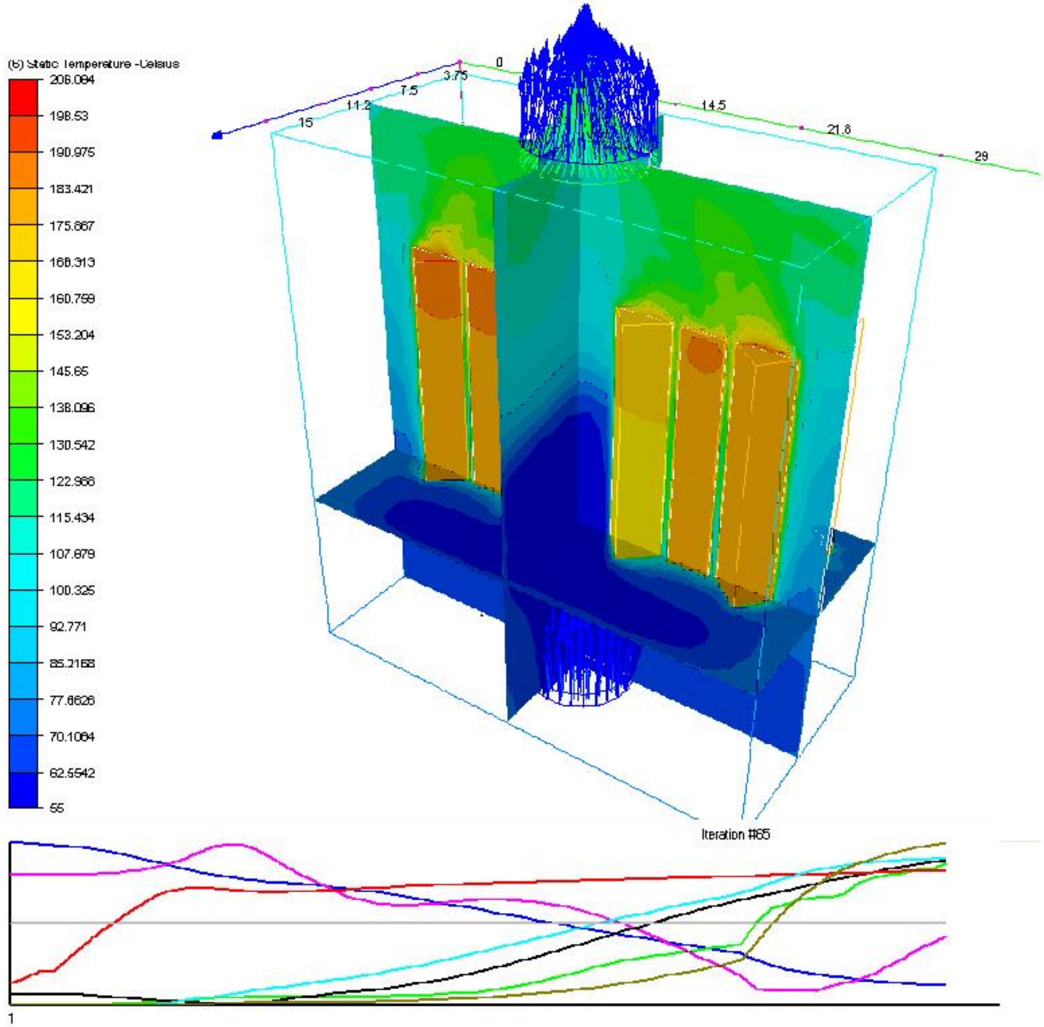
Shock & Vibration Consideration

Using ANSYS FEA modeling, this image shows the levels of stress over the surface of a steel housing. This modeling provides considerable insight towards qualifying assemblies to meet various shock and vibration requirements.



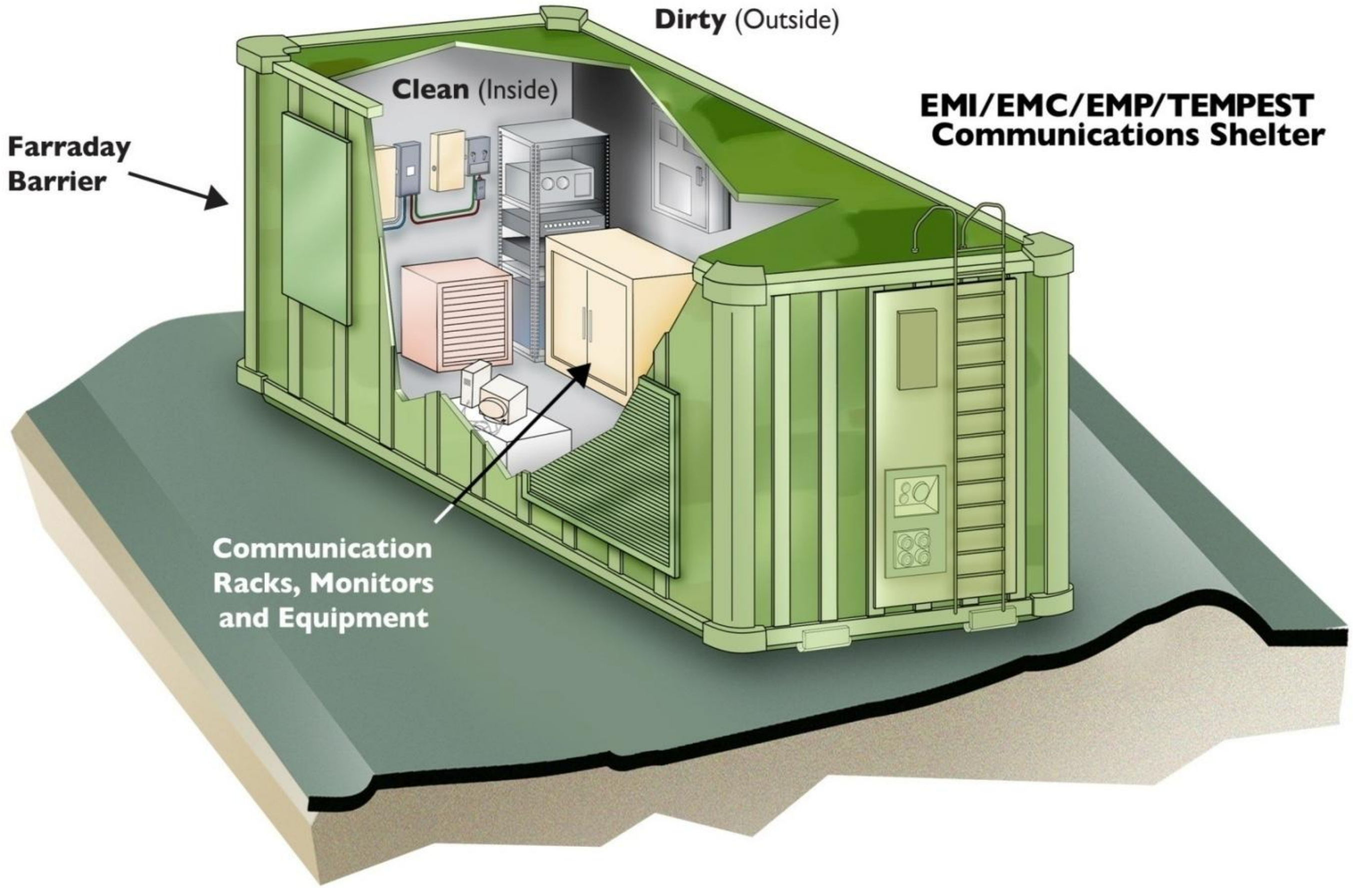


Thermal Effects



Using ANSYS FEA modeling, this image shows the thermal stress and operating temperature heat rise for a set of inductors in an AC HEMP service panel.

EMP Protection



EMP Protection: Transtector Components are a Crucial Element of the System Solution

Thank you for your time

Jason Koshy
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