APPLICATION NOTE

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EMP and Lightning Protection
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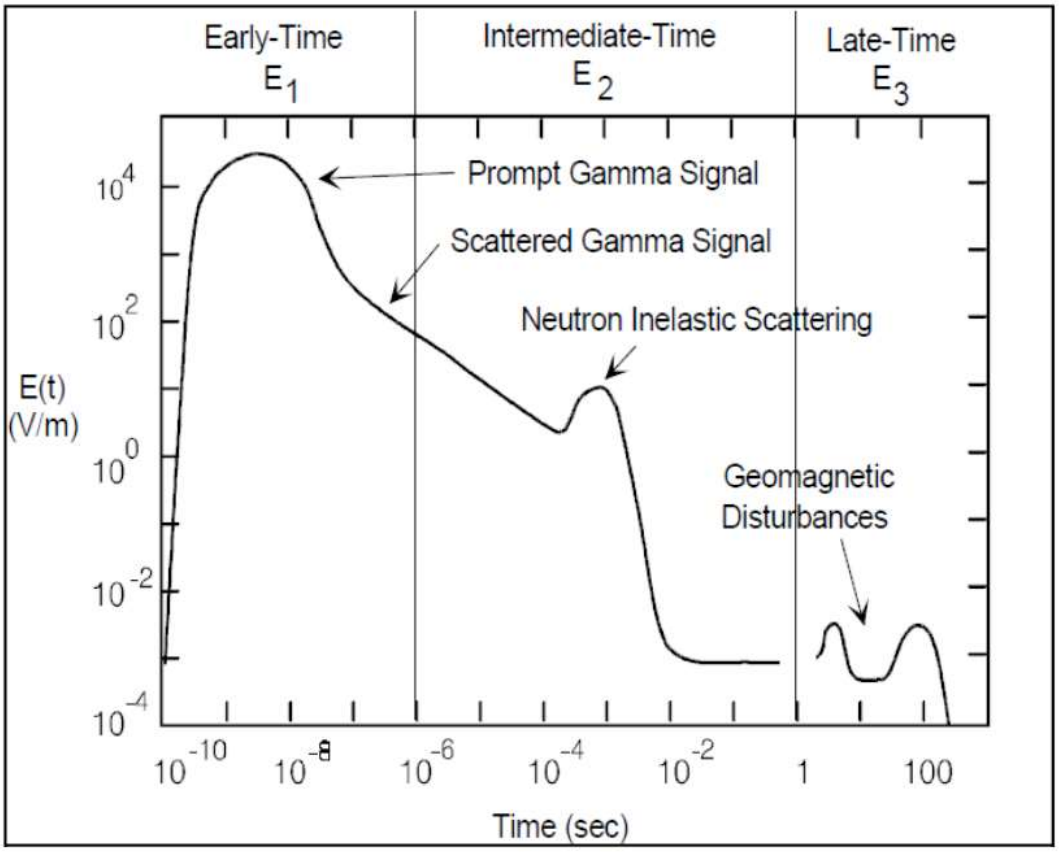
HEMP threat

Coupling of HEMP into RF-Antennas

Nuclear explosions in or above the earth's atmosphere generate an intense electromagnetic pulse (EMP) by the physical phenomenon known as "Compton effect or Compton scattering". This transient electromagnetic disturbance is called nuclear EMP or NEMP, while a detonation caused at an altitude above 40 km creates a pulse known as high altitude EMP (abbreviated as HEMP). The typical HEMP is defined as a combination of three consecutive pulses called early-time (E1), intermediate-time (E2), late-time (E3), as shown in the graph below.



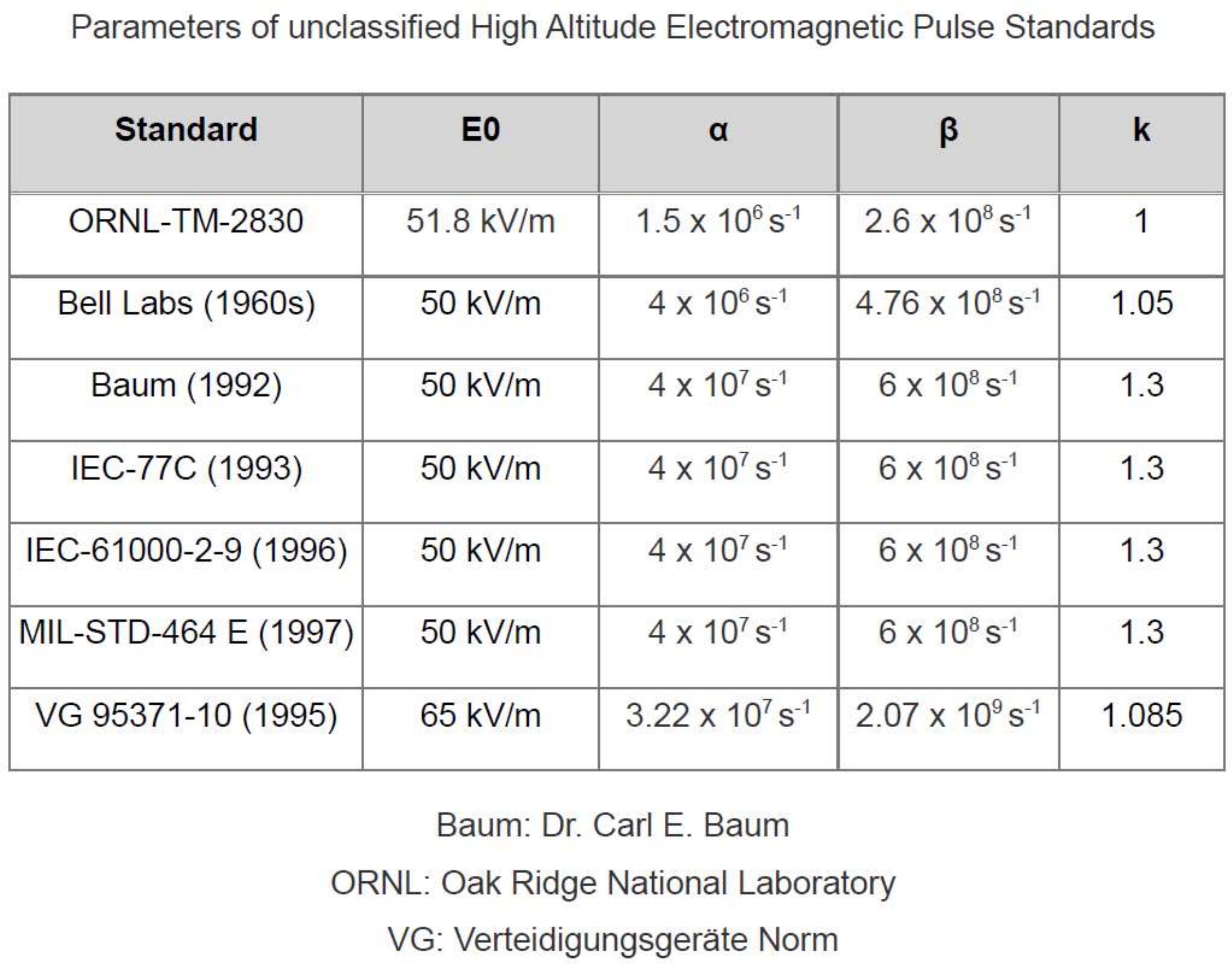
Source: EMP environnement MIL-STD-464

Depending on the altitude of the explosion and of the weapon design characteristics, the HEMP is distributed over a large or very large area. For a burst height of 40 km the HEMP is spread over an area of 1.6 x 10^6 km^2. When the burst height is 400 km, the HEMP will be spread over

15 x 10^6 km^2 on the earth's surface. The effects of the HEMP could lead to an upset or permanent damage of a sensitive electronic system. To take precaution against the effects of the electromagnetic pulse it is important to understand the coupling mechanism of the harmful electromagnetic fields onto RF systems.

For localized systems, such as a RF receivers or transmitters the dominating response mechanism is the early-time (E1) field. The intermediate-time (E2), and late-time (E3) field components become important for systems such as electrical power systems, in which conductors of several hundreds of kilometers exist and can effectively couple to these low-frequency fields. Therefore this paper only deals with the early-time (E1) HEMP environment.

$$E(t)=E_0\,k\,(e^{-\alpha t}-e^{-\beta t})$$



Parameters of unclassified High Altitude Electromagnetic Pulse Standards

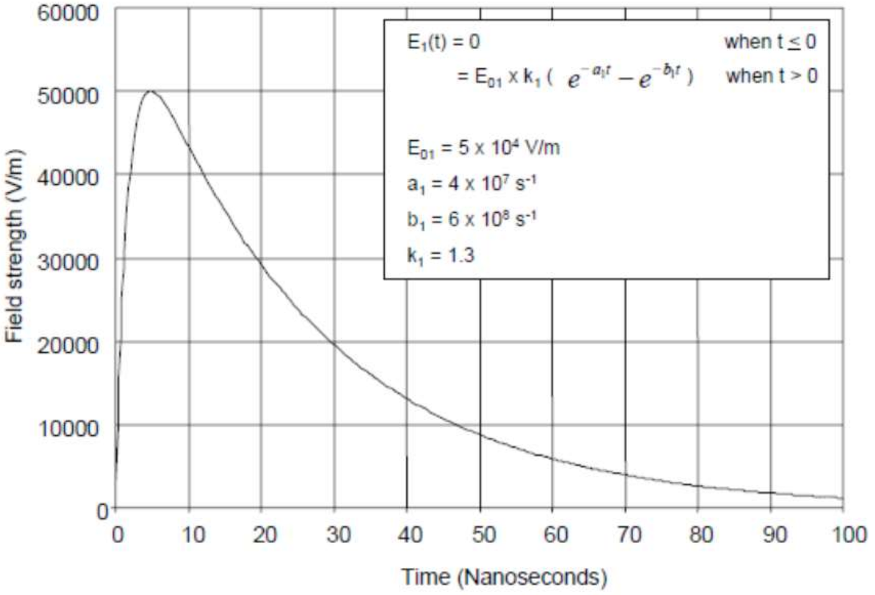
Standard	E0	α	β	k
ORNL-TM-2830	51.8 kV/m	1.5 x 10^6 s^{-1}	2.6 x 10^8 s^{-1}	1
Bell Labs (1960s)	50 kV/m	4 x 10^6 s^{-1}	4.76 x 10^8 s^{-1}	1.05
Baum (1992)	50 kV/m	4 x 10^7 s^{-1}	6 x 10^8 s^{-1}	1.3
IEC-77C (1993)	50 kV/m	4 x 10^7 s^{-1}	6 x 10^8 s^{-1}	1.3
IEC-61000-2-9 (1996)	50 kV/m	4 x 10^7 s^{-1}	6 x 10^8 s^{-1}	1.3
MIL-STD-464 E (1997)	50 kV/m	4 x 10^7 s^{-1}	6 x 10^8 s^{-1}	1.3
VG 95371-10 (1995)	65 kV/m	3.22 x 10^7 s^{-1}	2.07 x 10^9 s^{-1}	1.085

Baum: Dr. Carl E. Baum

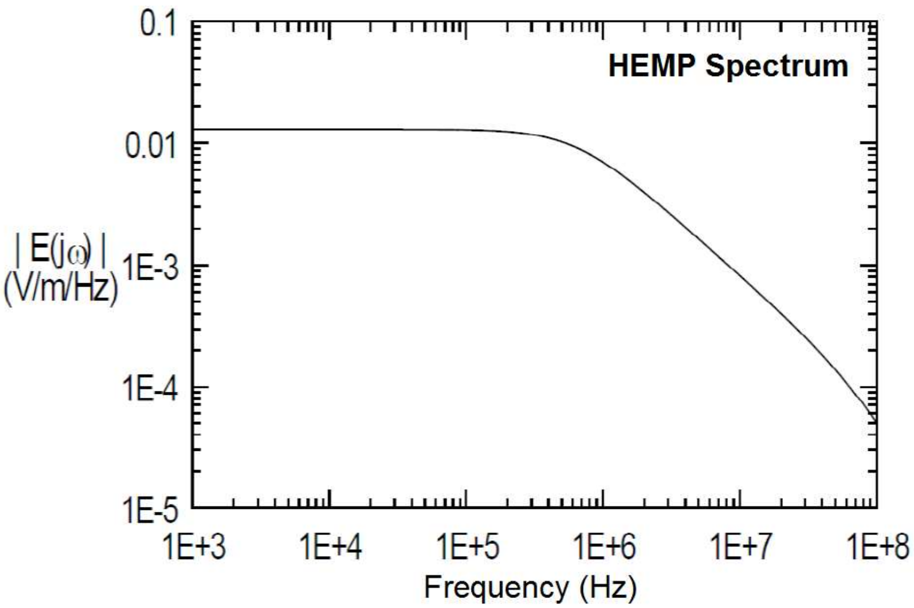
ORNL: Oak Ridge National Laboratory

VG: Verteidigungsgeräte Norm

Using the parameters defined by Carl Baum, by IEC or in the MIL-STD-464 leads to the equivalent double exponential transient HEMP pulse as shown below. The frequency spectrum of this transient is also shown.



Transient (H)EMP waveform (Baum, etc.)



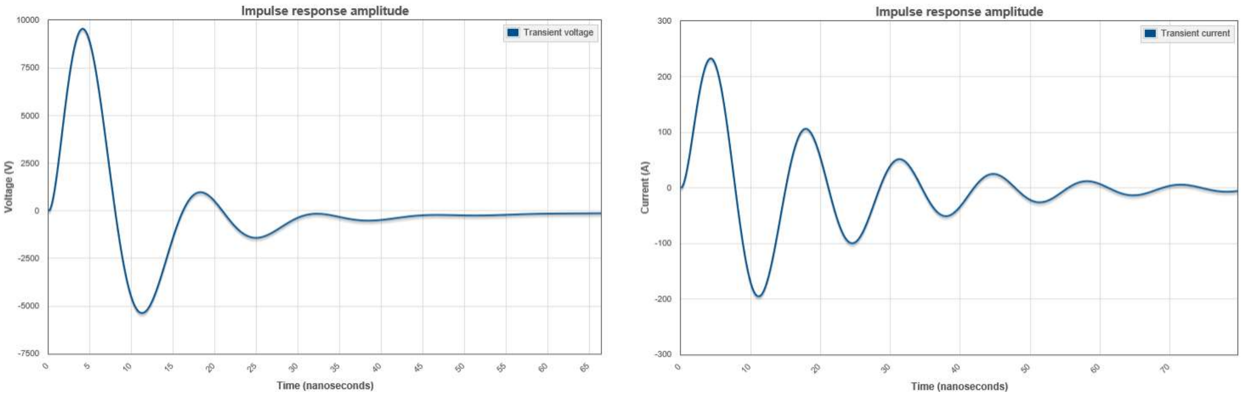
Frequency response of (H)EMP waveform

This fast rising transient electromagnetic field induce high voltage pulses in unprotected coaxial cables or antennas from where they can be directly lead to the ports of communication equipment.

Effects of the HEMP

The voltage peaks which can be induced into exposed electrical conductors, such as wires or antennas of communication equipment are far above the damage threshold level of most electronic components. Effects can be irreversible damage (burnout) or degrade (upset) of electrical and electronic equipment.

Worst case transient voltage / current at a 1 m monopole antenna



Calculated with EMP Protector Tool Box, http://empselector.hubersuhner.com/

EMP countermeasures

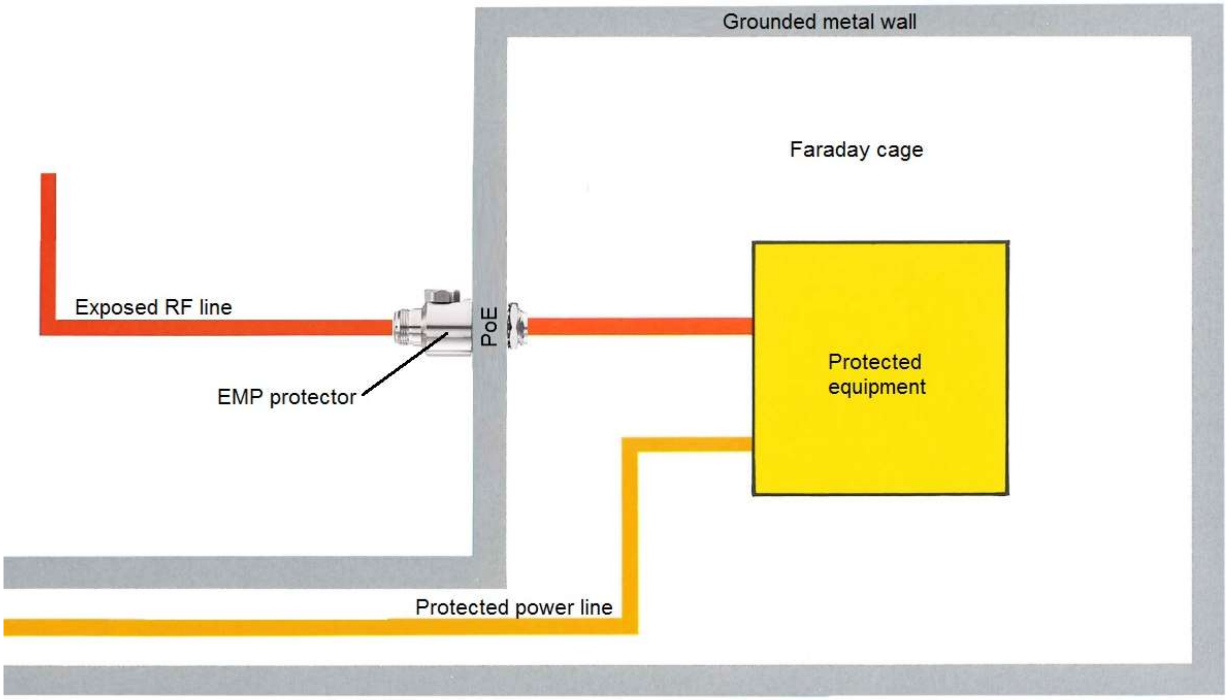
The two possible EMP countermeasures are screening (shielding) or grounding (diversion). The first part includes all measures which help to reduce the coupling of the EMP fields into the installation and equipment which has to be protected. Ideally it is represented by a Faraday cage or shielded room.

The second part includes all measures to reduce (attenuate) or eliminate disturbance signals (surges) by means of specially designed coaxial EMP protectors, limiters or surge protective devices (SPD).

These measures protect also against high power microwave (HPM). The HPM can be generated by radar systems, jammers, or special E-bombs.

EMP protected installation

EMP protection devices can only be effective if properly installed. Poor installation can reduce the effectiveness of the protection measure.
In defense applications, where the source of danger maybe lightning (LEMP) or the very fast HEMP it is mandatory to install EMP protectors with the bulkhead mounting principle as described in MIL-STD-188-125 and VG 95376-5. Both standards establish the minimum basic requirements and objectives for grounding, bonding and shielding of ground-based facilities including buildings and structures supporting tactical military communication systems.
The bulkhead mounting principles establishes a low inductance and resistance circumferentially connection between the EMP to the conductive mounting wall and keep the surge current on the outside of the cabinet, chassis or shelter wall.



Example of a protection concept

Power cabling systems
Power installations are exposed to considerable risk, although no sensitive components such as semiconductors are used. For mission critical installations protective measures are inevitable. Often integral protection cannot be realized for cost reasons. Practical solutions employ the partial protection concept.

Coaxial EMP protectors for application in the RF and microwave field
Protectors for these applications are produced using coaxial technology. During normal operation these devices shall not influence the RF behavior and signal which has to be protected. Surges generated by HEMP or other sources will be diverted to ground.

The major principles for coaxial EMP protective devices are:

1. Gas Discharge Tube (GDT) Technology
   As numerous communication lines carries RF signals (HF / VHF) in the HEMP frequency spectrum, gas discharge tube (GDT) technology have to be used.
   Due to its small capacitance and fast response time, the GDT technology can be used for broadband applications up to 6 GHz.
   A gas discharge tube can divert partial lightning strikes up to 30 kA (8/20 µs) to ground without being destroyed.

   The function based on the gas discharge principle. Ignition of an arc drops the resistance of the GDT from gigaohms to milliohms within an extremely short time and divert the surge pulse to ground. Amplitude and energy content of the residual pulse are dependent of the rise time (dÛ/dt) of the incident surge pulse and the response characteristic of the protection device.

2. Filter Technology (High Pass- or Bandpass Filter)
   Filter circuit, high pass- or quarter wave shorted stub (QWS) protectors can be used in the case of a sufficient distance of the operation frequency to the (H)EMP spectrum or if at least a very important part of the spectrum can be attenuated (diverted) effectively.

HUBER+SUHNER can also provide Limiters (combined GDT / filter units) to protect against high power microwave (HPM) in any frequency range.

Design

EMP protectors are designed as a coaxial feedthrough for bulkhead mounting device. A V-shaped RF washer of annealed copper makes a well-conductive connection between protector housing and shielding walls (Faraday cage).

Selection Criteria

The most important criteria for EMP protectors are the protective behavior and the RF properties. The protective behavior is characterized by the residual voltage / energy and the current handling capability. The RF performance is given by the frequency (bandwidth) as well as by return loss (RL) and insertion loss (IL) within this bandwidth.

Residual voltage (U_{res})

Assumed that the gas discharge tube (GDT) is mounted inductance-free within the EMP protector housing, the residual voltage (U_{res}) equals the dynamic spark-over voltage of the GDT. Depending upon the static spark-over voltage of the chosen GDT the incoming pulse would be attenuated. The output pulse of the EMP protector is called the residual pulse or the residual voltage. The dynamic spark-over voltage and consequently the amplitude of the residual voltage are dependent on the input pulses rise time (du/dt). The typical rise time of a HEMP equals to 1 kV/ns. The rise time of a typical lightning surge (LEMP) equals to 5 kA/µs.

Current handling capability

The current handling capability is defined by the impulse discharge current (Is). The values are given by the GDT manufacturer for specific standard pulse shapes (e.g. 8/20 µs acc. IEC or ITU).

RF performance

The RF performance of EMP protectors is given by the electrical and mechanical structure of the EMP protector and by the connector series. An important impact on the return loss specifications has the capacitance of the GDT.