

## Introduction

Electromagnetic threats have been recognized for almost a century. However, it is only in the past few decades that governments and military organizations have fully realized the dangers that intentional and unintentional electromagnetic interference (IEMI/UEMI) pose to critical facilities, infrastructure, aerospace systems, and land-mobile electronic systems. Most nations' electrical infrastructure and utilities are vulnerable to sabotage and intentional disruption using IEMI. Equally disruptive is the threat to digital and communications network infrastructure, such as data centers and internet systems, on which global banking, transportation, and resource allocation now depend.

The threat of IEMI, as well as UEMI and natural EMI, continues to grow as society becomes increasingly dependent on electrical systems to enhance efficiency, reduce costs, accelerate processes, and increase profits. Additionally, most modern electronics are built with low-power integrated circuits (ICs) and other sensitive components whose economics rely on miniaturization, reduced power consumption, and high levels of feature integration. Unfortunately, few nongovernmental or commercial organizations have recognized this threat, and even fewer have taken action to ensure their essential systems are protected against IEMI.

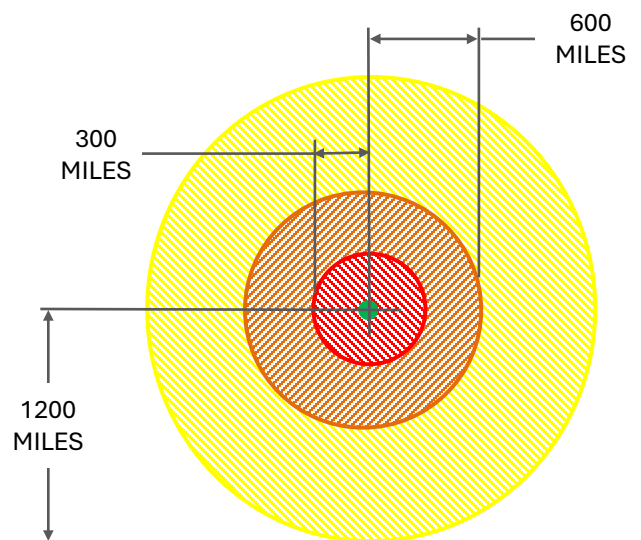
A small number of organizations have been actively studying and developing technologies to protect critical and sensitive electronic systems from the dangers of IEMI. As a result, a new class of EMI filters, known as electromagnetic pulse/high-altitude electromagnetic pulse (EMP/HEMP) filters, has emerged. EMP/HEMP filters are designed to protect electrical assemblies from IEMI while also suppressing other forms of harmful EMI.

## Overview of EMI, EMP, HEMP, GMS, CME, and Electronic Threats

The term *EMI* broadly refers to any unwanted signals that degrade or disrupt the intended performance of electrical equipment. EMI can be further divided into three categories: intentional, unintentional, and natural EMI, all of which can be destructive to electronic systems. Natural and unintentional EMI may be produced by naturally occurring phenomena, such as geomagnetic storms, interactions within Earth's magnetosphere, or solar coronal mass ejections (CMEs), as well as by poorly designed or damaged electronic systems.

Because the effects of multiple EMI sources can be cumulative, even a few relatively weak EMI generators can pose a hazard to nearby EMI-sensitive systems. Although natural and unintentional EMI are outside the primary scope of this work, the methods used to protect electronics from IEMI can also offer some degree of protection against these sources.

IEMI poses an increasingly significant risk to electrical systems as the threats associated with electronic warfare continue to grow. Several countries, most notably Russia and China, are actively developing weapons intended to disable even well-protected electrical systems and infrastructure. Although nuclear weapons are devastating within their immediate blast radius, the electromagnetic pulse (EMP) generated by a nuclear detonation can damage electronics over a far larger area, particularly when the detonation occurs at high altitude.



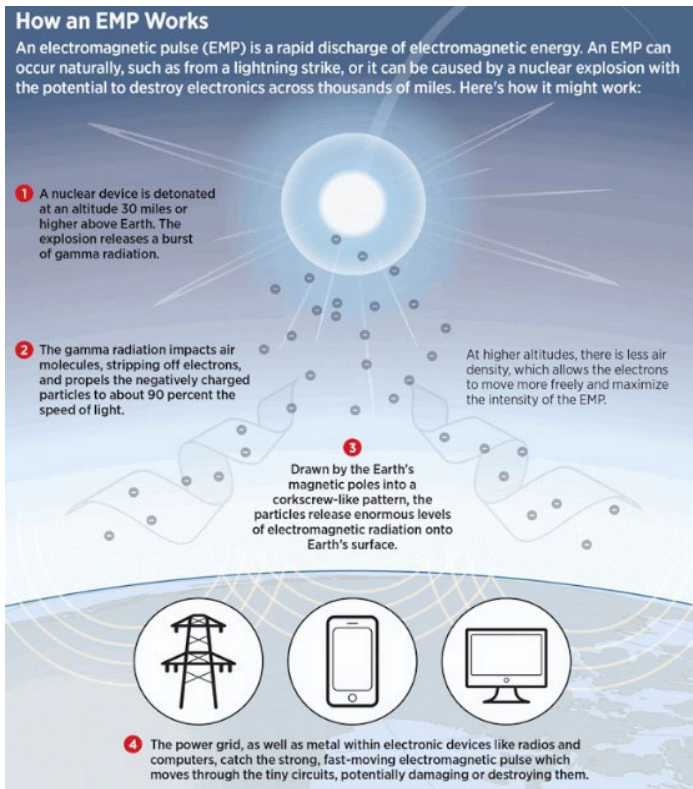
Line of sight from event occurring 250 miles (400 Km) above Earth's surface is approximately 1200 miles.

- RED 50Kv/M
- ORANGE 35Kv/M
- YELLOW 25Kv/M

\*Simulated blast configuration of 400 km altitude (above), not only considering Earth's magnetic field. A low altitude event would only show effects approximately 15 km. HEMP event over Kansas would affect ICs in systems from California to New York.

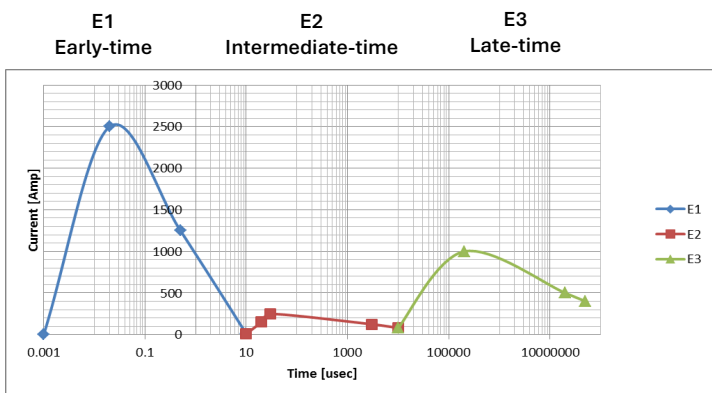
# Applications and the Evolution of EMP/ HEMP Filter Technologies

Even nuclear weapons detonated in space can emit severe, damaging radiation known as HEMP, which can affect ground-based electrical systems, aircraft, and vehicles. For this reason, nuclear EMP is used as a foundation for the development of modern standards and EMP protection systems. Nuclear EMP/HEMP threats are categorized by the IEC as E1, E2, and E3 components, each spanning a significant energy distribution from 1 MHz to 300 MHz. Each category includes a description of the type of EMI generated, along with guidelines on how to protect against it.



EMP/HEMP overview  
Source: The Heritage Foundation Research

## EMP Pulse Configuration per MIL-STD-188-125-1A

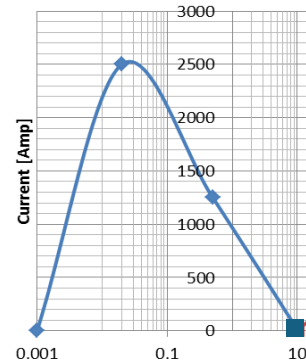


## E1 Component

The E1 pulse, or *short-pulse* component of a nuclear EMP, results from electrons being ejected from atoms in the upper atmosphere by the immense surge of gamma radiation produced during a nuclear explosion. These freed electrons are predominantly driven toward Earth, spreading across a large geographic area.

### E1 Pulse

- Very short duration, high energy
- 3 n-sec rise, 200 n-sec duration (half magnitude)



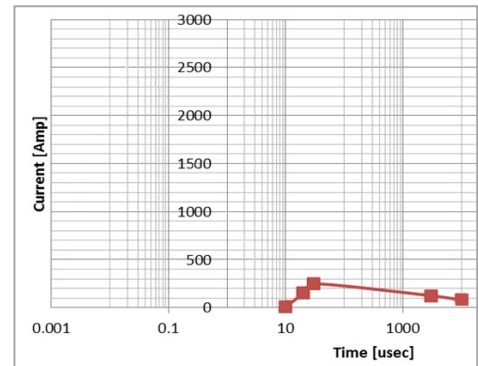
The E1 pulse manifests as a very intense but extremely short-duration burst of electromagnetic energy that can interact with conductors and induce high voltages. These induced voltages can easily exceed the breakdown ratings of conductors, electronic components, devices, and interconnects, leading to immediate and often irreversible damage.

## E2 Component

The E2 component, or *intermediate pulse*, is produced by scattered gamma rays and by inelastic gamma emissions generated through neutron interactions. This pulse shares many characteristics with the electromagnetic effects of a lightning strike; however, a nuclear E2 pulse typically exhibits a lower amplitude than that of an actual lightning event.

### E2 Pulse

- Amplitude and duration similar to lightning pulse
- 1.5  $\mu$ -sec rise, 3000 n-sec duration



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Although a system may already be protected against lightning, it can still be vulnerable to damage from an EMP-induced E2 pulse. Lightning protection devices and other circuit safeguards may be compromised or disabled by the preceding E1 pulse, or they may not have sufficient time to recover before the E2 pulse arrives. Additionally, the area of effect of an E2 pulse behaves more like the coupling caused by a nearby lightning strike, affecting a broad region of electrical systems, rather than the localized impact of a direct lightning strike.

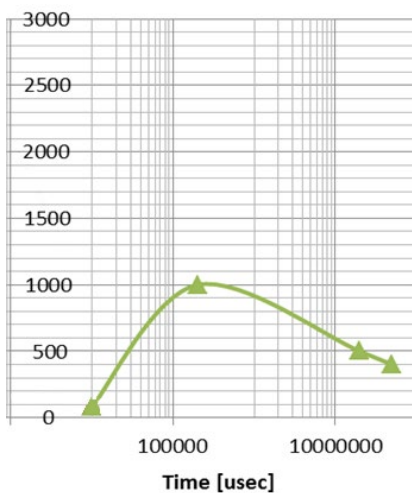
## E3 Component

Compared to the E1 and E2 components, the E3, or *long-time*, component is a relatively slow pulse that can last from tens to hundreds of seconds. The E3 pulse is generated by the gradual recovery of Earth's magnetic field following the high-energy disturbance created by a nuclear detonation. The E3 waveform consists of two subcomponents, E3a and E3b, commonly referred to as the *blast wave* and *heave wave*, respectively.

The behavior of the E3 pulse is often compared to the effects of a strong geomagnetic storm, such as one caused by a solar CME. Similar to geomagnetic storms, the E3 component can induce significant currents in long conductors, including underground cables and power transmission lines, potentially leading to widespread system damage.

### E3 Pulse

- Long duration
- 0.2 sec rise, 20 sec duration



The strength of the induced E3 current is related to the length of the conductors and can damage power line cables and equipment.

Unlike the E1 and E2 components, the energy induced in conductors by the E3 pulse resembles a quasi-DC signal, which can be especially damaging to AC power grid systems that are not designed to withstand high DC loading. These effects can generate peak currents of up to 1000 A and can cause damage through increased reactive power consumption, transformer saturation, and system misalignment resulting from harmonic disturbances.

## Basic Requirements of EMP/HEMP Filters

Most EMP/HEMP protection research, and the resulting classifications and standards, originates from studies conducted in the mid-1900s, before the widespread adoption of microprocessors and the proliferation of personal, commercial, and industrial electronic control and sensing systems. At the time, the primary concern was maintaining the stability and functionality of the electrical power grid.

Today, however, virtually every device and system, aircraft, automobiles, traffic control infrastructure, building safety systems, and even residential technologies, relies on electronic control and monitoring as an essential part of its operation. As a result, the potential impact of an EMP event on modern society extends far beyond the consequences of a severe power outage. Estimates suggest that societal and economic recovery times could range from several months to more than a decade.

This reinforces the need for protective devices that can safeguard critical systems down to the individual device or assembly level, not merely at the facility level. For electronic systems that do not contain long runs of electrical conductors, the primary concerns are the E1 and E2 pulses, which historically led to the development of standards focused on large rack-based and enclosure-based electronics. This gap has driven the emergence of IEMI filters enhanced for EMP/HEMP applications, which can be integrated directly into the design of virtually any critical electronic system.

Several standards, primarily governmental, military, and more recently those issued by the International Electrotechnical Commission (IEC), provide specifications for designing buildings, electrical infrastructure, and equipment capable of withstanding known IEMI threats. These standards focus mainly on nuclear electromagnetic pulse (EMP) phenomena, and specifically high-altitude nuclear EMP (HEMP).

For the United States and the United Kingdom, the primary military and governmental standards for facilities and equipment are MIL-STD-188-125-1A / MIL-STD-188-125-2A and DEF-STAN-59-188-1 / DEF-STAN-59-188-2, respectively.

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Part 1 (-1) of both nations' military HEMP standards addresses the protection of entire facilities. The focus includes subscriber terminals, data processing centers, transmitting and receiving communication stations, relay facilities, and other sites that support critical, time-urgent command, control, communications, computer, and intelligence (C4I) missions.

Part 2 (-2) of both standards addresses transportable, ground-based systems that support HEMP-hardened, critical, and time-urgent C4I networks. MIL-STD-188-125-2A and DEF-STAN-59-188-2 define the low-risk, HEMP-hardened design and testing criteria for these systems. Notably, these standards are written with the understanding that HEMP protection overlaps with and can satisfy related requirements, including emanation security, TEMPEST, EMI/electromagnetic compatibility (EMC), lightning protection, and other hardening disciplines.

A specific requirement in MIL-STD-188-125-2A states that transportable systems composed of separate transportable subsystems must be protected by an electromagnetic (EM) barrier. This barrier must include a HEMP shield as well as protective devices at all points-of-entry (POE), such as EMP/HEMP filters. DEF-STAN-59-188-2 follows a similar approach and aligns closely with the processes defined in the U.S. standard.

Other U.S. military standards relevant to HEMP include MIL-STD-464D, MIL-STD-461G, and MIL-STD-2169D, each of which contains both classified and unclassified sections. While these military standards are extremely thorough, they are not ideally suited for protecting commercial and industrial electronic systems, as they often assume the presence of additional military or governmental protections, infrastructure, and operational frameworks.

This need for broader, non-military guidance led IEC Subcommittee 77C to develop standards for protecting civil systems from HEMP and IEMI. Since 1999, the scope of IEC SC 77C has expanded to encompass all High-Powered Electromagnetic (HPEM) threats, including intentional electromagnetic interference. The IEC standards address definitions, methodologies, and applications related to EMP, HEMP, and IEMI threat mitigation.

These standards provide environmental descriptions, test and measurement techniques, and guidelines for implementing effective IEMI countermeasures. Together, the IEC civil-system HEMP and IEMI standards establish consistent, repeatable methodologies for evaluating the performance of mitigation technologies and ensuring reliable protection across a wide range of civilian infrastructure.

Military standards make several foundational assumptions that drive their protection requirements. One key assumption is that the threatened electrical equipment has no inherent immunity beyond what the standards prescribe. As a result, any HEMP/IEMI protection must fully account for all necessary mitigation measures. This assumption does not always hold for civil applications, where existing EMC standards already require a baseline level of immunity.

Furthermore, military standards are designed to prevent *any* interruption of function, whereas many civil systems can tolerate limited disruption as long as they are able to recover after the HEMP/IEMI event. For this reason, adherence to relevant IEC standards may offer a more cost-effective approach for specifying HEMP/IEMI filter performance in non-military environments. Ultimately, the appropriate standard depends on the required severity level of protection and the specific operational needs of the civil system.

IEC protection severity levels (IEC 61000-4-24) address a broad range of equipment types and applications, spanning from levels equivalent to MIL-STD-188-125-1A and DEF-STAN-59-188-1 to those appropriate for less critical civil systems. Severity Level 3, which corresponds to military and defense standards, is intended for the most critical infrastructure. Level 2 is designed for moderately critical civil infrastructure, while Level 1 applies to industrial systems that are either less critical or possess a high degree of inherent immunity.

The IEC 61000-4-24 standard provides recommendations for the residual pulse performance of HEMP/IEMI filters with respect to *conducted* pulses. However, it does not define or address shielding requirements for *radiated* pulses, which must be managed through separate standards and mitigation approaches.

For new buildings designed to meet Severity Levels 1, 2, or 3, a reasonable target attenuation level for HEMP/IEMI filters is 60 to 80 dB across the frequency range of 1 MHz to 1 GHz. For older buildings operating at Severity Levels 1 or 2, an attenuation level of approximately 40 dB may be sufficient.

## EMP/HEMP Filter Applications

As with virtually all electronic performance requirements, the necessary behavior of a device is ultimately dictated by its application. Many emerging technologies, such as self-driving and electric vehicles, wireless subsystem connectivity within aircraft, the Internet of Things (IoT), and Industry 4.0 systems, will increasingly depend on continuous connectivity. As these technologies become integral to modern

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infrastructure and daily life, they will, by extension, evolve into critical systems for society.

Currently, many financial, commercial, consumer, public safety, and emergency response systems rely on, or are significantly enhanced by, data and networking infrastructure, which is likely vulnerable to HEMP/IEMI threats. These vulnerabilities extend to the medical sector as well, where both infrastructure and equipment are increasingly dependent on electronic systems and continuous communication.

Doctors, nurses, and medical support personnel rely heavily on in-hospital patient monitoring systems, ambulance communications, and a growing range of in-home monitoring, mobility, and care technologies. As these systems become more interconnected and essential, their susceptibility to electromagnetic threats poses an even greater risk to public health and safety.

At Risk Electronics Systems / Equipment Type	Risks and Risk Level		
	E3 or GMS	E1/E2	IEMI
Hand-held and personal	None	Medium	High
Aircraft, ship, vehicle	None	Medium	High
Control systems, SCADA	Low	High	High
Data center equipment	Low	High	High
Communications networking and data lines	High	High	High
Electrical power grid	High	High	High

\*Source: HEMP/IEMI Update – The Threat and Concerns Presented to IEEE EMC Society Chicago Chapter Meeting November 18,2015

Although these applications are governed by their respective EMC standards, typically based on the perceived impact of system failure, traditional EMC standards alone are generally inadequate for protecting against HEMP/IEMI threats. EMC standards are designed primarily to limit interference, not to ensure survivability or suppress high-powered electromagnetic (HPEM) pulses and transients to levels that allow continued system operation. Most EMC standards focus on unintentional interference and do not account for deliberate IEMI attacks from malicious actors.

For example, data center equipment designed only to

meet standard EMC requirements is unlikely to be protected from corporate sabotage, terrorism, or collateral exposure to a wide-area EMP resulting from an attack on nearby utility infrastructure.

Electronics Equipment at Risk from IEMI and HEMP	Immunity Standard Power Levels (V/m)
Aircraft	7,000
Military Equipment	200
Automobiles	100
Network and Telephone Equipment	10
IT Equipment	10
Medical Equipment	10

\*Source: HEMP/IEMI Update – The Threat and Concerns Presented to IEEE EMC Society Chicago Chapter Meeting November 18,2015

Many modern civil systems remain vulnerable to HEMP/IEMI, including emerging applications where electromagnetic protection is not yet widely considered. These may include transportation systems for both freight and passengers, new small-satellite platforms and their associated ground equipment, industrial or commercial electronics repurposed for critical functions, and renewable energy systems. Numerous remote facilities depend heavily on renewable or onsite power generation, along with satellite and other telecommunications links, dependencies that also extend to civil nautical and maritime systems. As these technologies become increasingly essential, their exposure to HEMP/IEMI threats represents a growing concern.

Many arguments against adopting additional HEMP/IEMI protection have traditionally stemmed from ignorance of the threat, concerns over cost, unfamiliarity with sourcing channels, and limited access to knowledgeable and credible experts. However, growing international awareness and rising concern over HEMP/IEMI vulnerabilities are rapidly diminishing these objections. New sources of military-grade and custom-designed HEMP/IEMI filters are now emerging, making advanced protection solutions more accessible.

With modern compact design methods and advanced assembly techniques, HEMP/IEMI filters can be manufactured small and lightweight enough to be practical for aerospace and commercial aircraft applications, further broadening their viability across critical industries.

## **Conclusion**

Increasing individual and societal dependence on civil electronic and communications infrastructure is likely to heighten the risk of loss of life and property damage resulting from the failure of modern commercial and industrial electronic systems. Particularly vulnerable are the latest integrated circuits and low-power electronics, which are often exposed due to inadequate shielding, as well as the emerging technologies that depend on them. Many of these systems can benefit from enhanced protection—specifically the use of HEMP/IEMI filters, which can also improve general EMI immunity.

As new threats continue to emerge alongside rapidly evolving technologies, the integration of HEMP/IEMI filters offers a practical and forward-looking approach to protecting both current and future investments in the digital age.