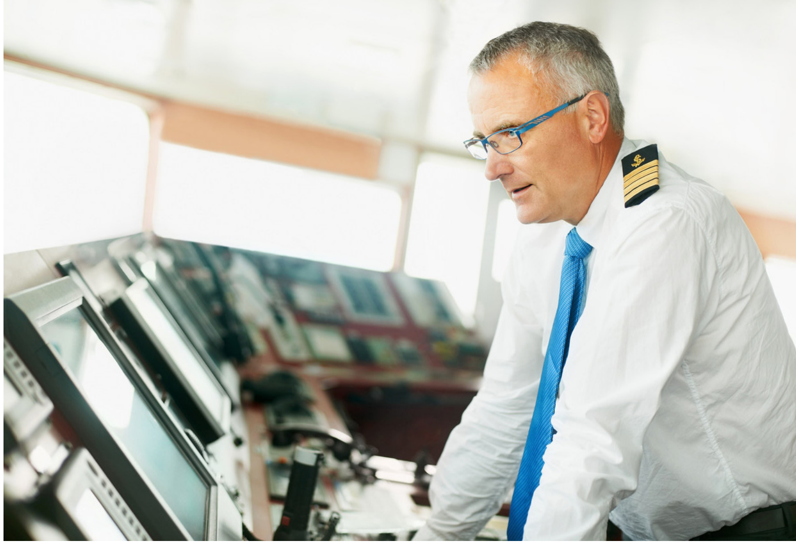
Applications and the Evolution of EMP/HEMP Filter Technologies Designed to Mitigate Naturally Occurring EMI and Intentional EMI Threats



api technologies corp.

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Introduction

Electromagnetic threats have been known, and to a degree understood, for almost a century. Nevertheless, it is only in the past couple of decades that governments and military organizations have come to realize the extent of the threat that intentional/unintentional electromagnetic interference (IEMI/UEMI) pose to critical facilities, infrastructure, aerospace, and land mobile electronic systems. Most nation's electrical infrastructure and utilities have been identified as vulnerable to sabotage and intentional disruption using IEMI, the threat to these systems has been a known entity for many years. What is an emerging unknown, and possibly equally as disruptive, is the new threat to digital and communications network infrastructure (data centers and internet systems) that the world's banking, transportation, and resource allocation now relies on.

The threat of IEMI, and even UEMI and natural EMI, on every level of a modern society only grows, as people become more dependent on electrical systems to enhance efficiency, reduce expenditures, speed processes, and raise profits. Additionally, the most recent electronics are built with low power Integrated Circuits (ICs) and other sensitive active and passive devices whose economics depend on miniaturization, power reduction, and feature integration. Unfortunately, few non-governmental/military organizations have come to recognize this threat, and fewer have taken action to ensure their essential systems, for which many other organizations and individuals depend, are robust toward IEMI, or EMI in general.

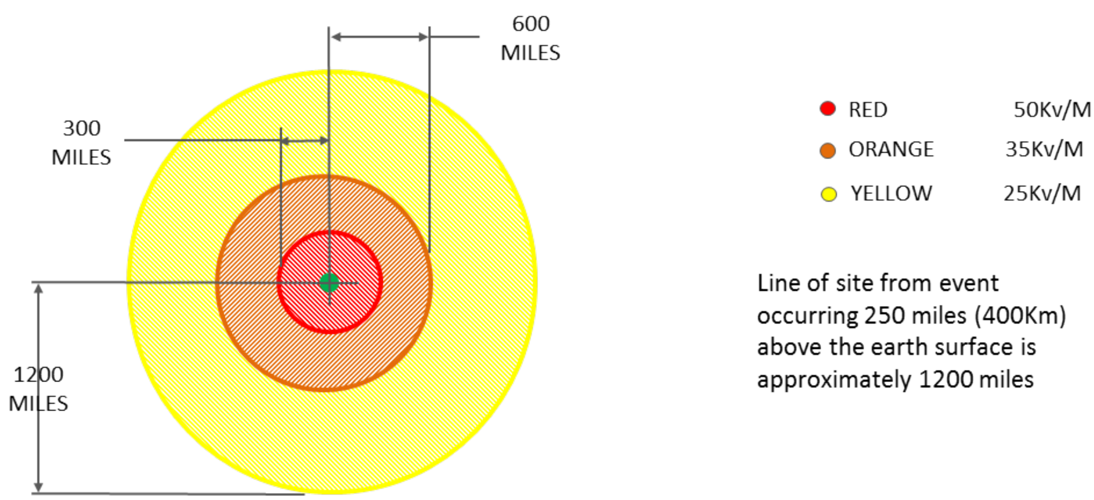
Notwithstanding the general blind eye, there are a few organizations that have been studying and developing technologies to protect critical and sensitive electronic systems from the dangers of IEMI and EMI. Where most prior efforts have been in the protection of buildings and racks of electronic equipment, a new breed of EMI filters, electromagnetic pulse/high altitude electromagnetic pulse (EMP/HEMP) or IEMI filters are now available. EMP/HEMP filters are designed to protect specific electrical assemblies, or sub-assemblies, from IEMI and ensure that these susceptible electrical systems benefit from not only survivability, but suppression of harmful EMI.

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

The term EMI broadly applies to any unwanted signals that degrade or disrupt the desired performance of electrical equipment. EMI can be further broken down into three categories, intentional, unintentional EMI, and natural EMI, all of which can be destructive to electronics. Natural and Unintentional EMI can be produced by naturally occurring sources, such as geomagnetic storms caused by weather patterns and the interaction of the earth's electro magnetosphere and space weather--solar coronal mass ejections (CME)--, or by a number of poorly planned/designed or damaged electronic systems. As the effects of several EMI generators can be cumulative, even several relatively weak EMI generators could pose a hazard if in close proximity to a EMI sensitive system.

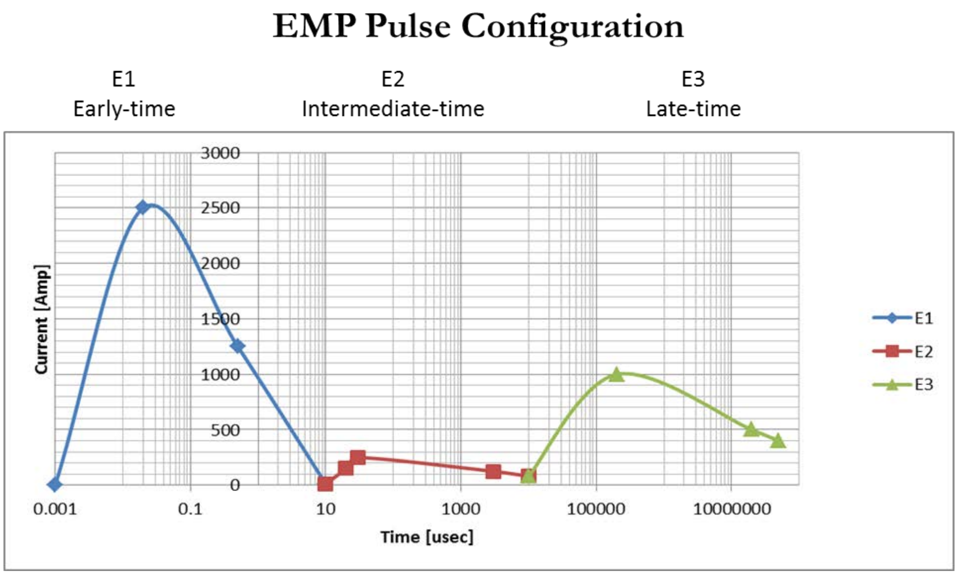
Natural and unintentional EMI are outside of the scope of this work. However, the methods of protecting electronics from IEMI can also provide some protection from natural and unintentional EMI sources.

The potential threat of IEMI is hard to gauge, as malicious, or even ignorant, parties could produce EMI that could affect different electrical systems in a variety of ways. IEMI is a risk to electrical systems which is only increasing as access to EM weapons is only becoming easier. There are several countries, namely Russia and China, who are actively developing EM weapons designed to disable even protected electrical systems and infrastructure. Though nuclear weapons are destructive enough in their immediate blast radius, there is also an EMP component of a nuclear blast that can be destructive toward electronics over a much wider area than what was affected by the nuclear blast.



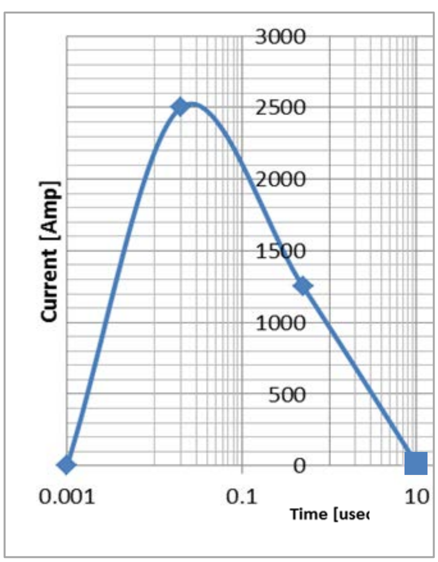
**Simulated blast configuration at 400 km altitude (above), not only taking into account the Earth's magnetic field. A low altitude event would only show effects out approximately 15 km. HEMP event over Kansas would affect ICs in systems from California to New York*

Even nuclear weapons detonated in space can emit severe and damaging radiation, known as HEMP, which can even affect ground based electrical systems, aircraft, and vehicles. This is why nuclear EMP is used as a basis for the development of standards and EMP protection systems. Nuclear EMP/HEMP threats are classified by the IEC as E1, E2, and E3 components, and have a dominant energy distribution from 1 MHz to 300 MHz. Each component classification comes with a description of the type of EMI that is generated and guidelines on how to protect against it.



The E1 Component

The E1 pulse, or short pulse, component of nuclear EMP is a result of electrons being ejected from atoms in the upper atmosphere due to the huge initial surge of gamma radiation from a nuclear explosion. A product of the interaction of these highly accelerated electrons and the earth's magnetic field, the stray electrons are predominantly directed toward the earth over a large affected area. The E1 pulse acts as a very intense, but short duration, blast of relativistic speed electrons, which are capable of interacting with conductors and producing high voltages in those conductors. These voltages can easily exceed the electrical breakdown voltages of the conductors and connected electronic components, devices, and interconnects.



E1 Pulse

- High current
- Short duration
- Initial high amplitude
- Fast transient event
- 2500A, 20n-sec rise, 500 n-sec

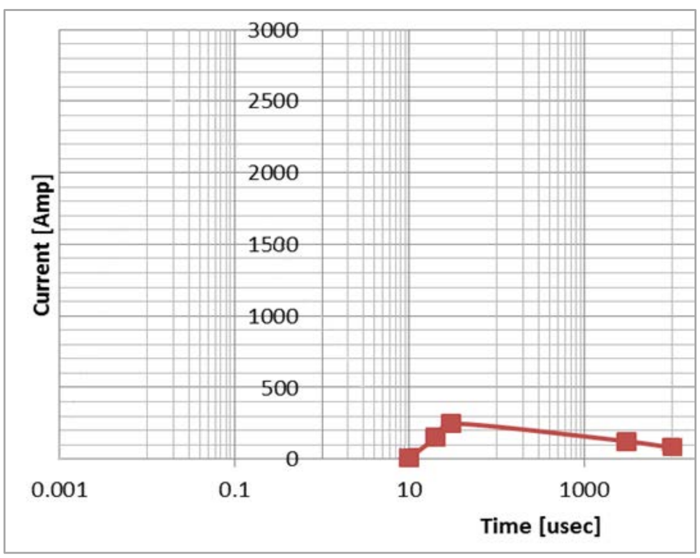
Typically, the E1 pulse is too brief for traditional lightning protection to be effective, and only transient protection that can respond to extremely fast rise-time pulses is capable of mitigating

E1 EMP. The E1 pulse has a typical rise time of 20 nanoseconds, and reaches 50% of its peak value in 500 nanoseconds, and by the IEC's definition, completely occurs within 1 microsecond. The critical frequency range for the E1 pulse is between 1 MHz and 300 MHz. The electric field strength of the E1 pulse peaks at roughly 50,000 Volts per meter, with peak power densities reaching 6.6 Megawatts per square meter. Depending on a variety of factors, the peak current induced into an electrical system from an E1 pulse could reach 2500A. The E1 pulse is the most dangerous of the HEMP pulses toward smaller electronics and electrical system not connected to long conductor lines, still damaging integrated circuits.

The E2 Component

The E2, or intermediate pulse component, of a nuclear weapon is somewhat similar to the pulse generated by a nearby lightning strike, though the E2 component of a nuclear strike presents less power than a lightning strike. The E2 pulse is produced when the nuclear weapon emits neutrons that then scatter gamma rays and produce radiation from inelastic scattering. According to the IEC definition, the E2 pulse starts after one microsecond from the initial EMP blast, and extends to one second post blast.

The E2 pulse can hit a peak current to 250A, and contains more energy than the E1 pulse, which is spread over a longer time frame. The frequency of EM radiation from the E2 pulse is also much lower than the E1 pulse, down to 20 kHz, and presents a higher attenuation and lower penetration capability for small apertures and electrical conductors shorter than 200 meters. It is generally considered that the E2 pulse can be protected against, and is protected against, by current lightning protection circuitry.



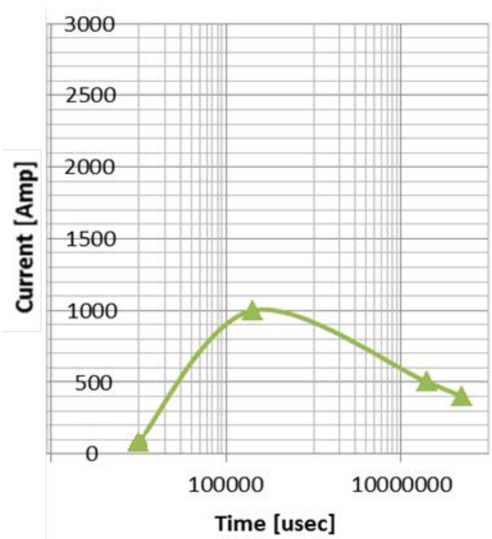
E2 Pulse

- Amplitude and duration similar to lightning pulse
- 1.5 u-sec rise, 3000 n-sec duration

However, this protection doesn't necessarily eliminate the threat, as the lightning protection, and other circuit protections, could be damaged by the E1 pulse, or not have time to recover and adequately protect against the E2 pulse. Also, the area of effect of an E2 pulse isn't isolated to the small area of impact of a direct lightning strike, and behaves more like how a nearby lightning strike couples into electrical systems.

The E3 Component

Compared to the E1 and E2 components, the E3, or long-time component, is a relatively slow pulse, which can last from tens to hundreds of seconds. The E3 pulse is generated from the recovery of the Earth's magnetic field in response to the high energy disturbance of the nuclear strike. There are two subcomponents of the E3 waveform, E3a and E3b, known as the blast wave and heave wave respectively. The E3 pulse behavior has been compared to the effects of a strong geomagnetic storm, such as that from a solar CME. Similar to a geomagnetic storm, the E3 component can induce potentially substantial currents in long conductors.



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 lead to damage and destruction of power line cables and equipment. Unlike the E1 and E2 components, the energy generated in a conductor by the E3 pulse more resembles a quasi-DC pulse, which can be particularly damaging to AC power grid systems not designed to handle high DC loads. These effects can cause damage from the increased reactive power consumption and misalignment of systems from harmonic disturbances while reaching peak currents to 1000A. Additionally, the E3 pulse is capable of inducing currents even in long underground cable and power lines.

The Basic Requirements of EMP/HEMP Filters

The majority of EMP/HEMP protection studies, and the basis the EMP/HEMP classifications and standards, are based on studies performed in the middle of the last century. These studies were performed prior to the major adoption of microprocessors, personal, and commercial/industrial electrical control and sensing. The major concern at the time was the maintenance of the electrical power grid. Now, every device or system, from aircraft, cars, traffic lights, office building safety systems, and even homes, is electronically controlled and monitored as an essential part of these systems' operational dynamics. Therefore the current threat to modern society is much greater than a severe power outage, and societal and economic recovery times are estimated to range from matter of months to possibly over a decade.

This enforces the need for devices which are capable of protecting these smaller critical systems and not merely at a facility level, but at the device, or assembly, level. The main concerns for electronic systems that don't have substantial runs of electrical conductors are the E1 and E2 pulses, for which standards were developed for large rack-based and enclosure-based electronics. Hence, the advent of IEMI filters enhanced for EMP/HEMP applications, which can be integrated into the design of virtually any critical electronic system.

There are several standards, mostly governmental, military, and recently International Electrotechnical Commission (IEC), which provide specifications on how to design building, electrical infrastructure, and equipment to withstand known IEMI threats, mainly nuclear electromagnetic pulse (EMP), and specifically, high altitude nuclear EMP (HEMP). The main military and governmental standards for facilities and equipment for the US and the UK are MIL-STD-188-125-1/MIL-STD-188-125-2 and DEF-STAN-59-188-1/DEF-STAN-59-188-2, respectively.

Part 1 of both military's HEMP standards cover the protection of entire facilities, where part 2 for both standards covers the protection of transportable and mobile systems. The focus of the first parts of both standards includes subscriber terminals, data processing centers, transmitting and receiving communications stations, relay facilities, and facilities that otherwise perform critical, time-urgent command, control, communications, computer, and intelligence (C4I) missions.

Part 2 of both standards similarly applies to transportable ground-based systems for HEMP-hardened, critical, and time-urgent C4I networks. MIL-STD-188-125-2 and DEF-STAN-59-188-2 describe the low-risk, HEMP-hardened design and testing criteria for these systems. An important note is that these standards account for integration with related requirements, and recognize that HEMP protection can also meet criteria for emanation security, TEMPEST, EMI/electromagnetic compatibility (EMC), lightning protection, and other hardening requirements. A specific declaration in MIL-STD-188-125-2 is that for transportable systems made up of separate transportable subsystems must also be protected with an EM barrier, consisting of a HEMP shield and protective devices for all points-of-entry (POE). This includes EMP/HEMP filters. DEF-STAN-59-188 Part 2 follows a similar process as MIL-STD-125-188-2. Other US military standards applicable to HEMP include MIL-STD-464A, MIL-STD-461D/E/F, and MIL-STD-2169, of which there are classified and unclassified components.
Though extremely thorough, these military standards aren't the most suited to protecting commercial and industrial electronic systems, as the basis for many of these standards assumes other military and governmental protections, guidelines, and structure.

This is why the IEC, specifically IEC subcommittee 77C, developed standards for protecting civil systems from HEMP and IEMI. Since 1999, the scope of IEC SC 77C has expanded to include all High-Powered Electromagnetics (HPEM) threats, including IEMI. The IEC standards cover definitions, methodology, and application of EMP, HEMP, and IEMI threat mitigation. These standards include environmental descriptions, test and measurement techniques, and guidelines for installing and mitigating IEMI. Previously, many HEMP and IEMI filters leveraged a variety of military standards, and the IEC civil systems HEMP and IEMI standards help to establish consistent and repeatable methodology for determining the performance of IEMI and HEMP mitigation technologies.

The military standards make several assumptions, for which the requirements are based. This includes the assumption that the threatened electrical equipment has no immunity outside of the required protections. Hence, any HEMP/IEMI protection would have to completely account for the necessary mitigation. This isn't the case for some civil applications, and the already required EMC standards lead to requirements for at least some level of immunity. Moreover, military standards are designed to prevent any interruption, where many civil systems are likely to be able to afford some level of disruption, as long as they recover after the HEMP/IEMI incident. Therefore, maintaining IEC standards for some civil equipment could be a more cost effective guidance for HEMP/IEMI filter performance. This, of course, will depend on the severity level of protection required, and the specifications of the particular civil system.

IEC protection severity levels (IEC 61000-4-24) account for a variety of equipment and applications, extending from equivalence to MIL-STD-188-125-1 and DEF-STAN-59-188-1, to less critical civil systems. Severity Level 3, which is equivalent to military and defense standards, is meant to apply to the most critical infrastructure systems, where level 2 is designed for less critical infrastructure, and level 1 is for industrial applications that are either less critical, or possess a high level of intrinsic immunity. The IEC 61000-4-24 standard provides recommendations for the residual pulse performance of HEMP/IEMI filters in respect to conducted pulses, and does not define, or account, for radiated pulse shielding requirements.

A reasonable target figure for HEMP/IEMI filter attenuation to meet over the frequency range 1 MHz to 1 GHz for severity levels 1/2 and 3 for new building is 60 dB and 80 dB. For older building and severity level 1/2, 40 dB of attenuation may suffice. IEC 61000-4-24 also provides peak residual current level recommendations for each severity level. For a 250 VAC HEMP power line filter with a 2 Ohm nominal load for level 1, 2, and 3 severity levels, the peak allowable residual current into the load is 353 A, 50 A, and 10 A, respectively.

EMP/HEMP Filter Applications

As is the case for virtually all electronic performance requirements, the necessary behavior of a device is truly dictated by the application. Many emerging applications, such as self-driving/electric vehicles, wireless subsystem connectivity within aircraft, Internet of Things (IoT), and Industry 4.0 systems are likely to depend on constant connectivity and become critical systems for modern society. Currently, much of the financial, commercial, consumer, public safety, and emergency response systems depend, or are significantly enhanced, by the data and networking infrastructure, which is likely vulnerable to HEMP/IEMI threats.

Moreover, these trends are also seen with the medical infrastructure and medical equipment, with doctors and nurses relying more on medical electronics and communication systems. This includes in-hospital patient monitoring systems and ambulances, as well as in-home monitoring, mobility, and care systems.

At Risk Electronics System/Equipment Type	Risks and Risk Level		
	E3 or GMS	**E1/E2**	**IEMI**
Hand-held and personal	None	Medium	High
Aircraft, ship, or 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

Though all of these applications are also accompanied by their associated EMC standards, often based on perceived impact of system failure, typical EMC standards are likely inadequate to protect against HEMP/IEMI threats. EMC standards are predominantly designed to prevent interference to an extent, not for survivability and suppression of HPEM pulses and transients to the point of continued operation. Most EMC standards focus predominantly on unintended interference, and don't account for IEMI from malicious parties. For example, data center equipment isn't likely protected based on EMC standards from corporate sabotage, terrorism, or being caught in the crossfire of a nearby utility target by a wide area EMP.

Electronics Equipment at Risk from IEMI and HEMP	Immunity Standard Power Levels (V/m)
Aircraft	7,200
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

Hence, there are many current civil systems that are vulnerable to HEMP/IEMI, some of which may be emerging and new applications where HEMP/IEMI protection isn't commonly considered. This could include transportation for freight and passengers, new small satellite space and ground equipment, industrial and commercial electronics repurposed for critical applications, and renewable energy systems. Many remote facilities rely on renewable energy and onsite energy generation for operation, as well as satellite and telecommunications, which includes civil nautical/maritime systems.

Many of the arguments against leveraging additional HEMP/IEMI protection have been ignorance, concerns over costs, lack of familiar sourcing channels, and limited access to knowledgeable and credible experts. Growing international awareness and concern over HEMP/IEMI threats are rapidly eliminating many of these objections, and new sources of military grade, and custom design, HEMP/IEMI filters are becoming available. With highly compact designs and assembly techniques, HEMP/IEMI filters can also be made small and light enough to be viable in aerospace and commercial aircraft applications.

Conclusion

Increasing individual and societal dependence on the civil electronic and communications infrastructure is likely to also increase the threat of loss of life and property damage from the failure of new commercial and industrial electronic systems. Particularly susceptible are the latest Integrated Circuits and low power electronics exposed by inadequate shielding, and the emerging technologies that rely on them. Many of these systems could benefit from additional protection, specifically HEMP/IEMI filters, which may also aid in enhancing EMC emissions and immunity. As new threats continually emerge alongside new enabling technologies, leverage HEMP/IEMI filters is a practical way of protecting current, and future, investments in the digital age.