

EMP GENERATION MECHANISM AND ITS DESTRUCTIVE EFFECT ON C³I NETWORK

Dr. K K Jha

Defence Electronics Application Laboratory
Dehradun

Abstract

Command, control, communication and intelligence network for defence are becoming reliant on automated systems by taking advantage of modern electrical and electronic technology. The state-of-the-art computerized systems opted for expeditious, reliable and cost-effective services are, however, increasingly susceptible to upset or permanent damage due to the destructive effect of electromagnetic pulse (EMP). This paper discusses the mechanisms of EMP generation, its destructive effect and protection methods for C³I network.

Introduction

The wide band technological advancements in computer and electronic systems and our dependence on them has ensured in one hand the quality of service while on the other hand the limitless vulnerability due to variety of threats, like destructive electromagnetic pulse (EMP) has drawn global interest in developing the appropriate protection mechanism. The first experiment conducted by U S A in 1962 brought out that EMP a bi-product of high altitude nuclear burst has a damage potential to upset or damage permanently the electronic system operating at a distance, roughly 1200 Km away [Rudie, 1976]. The frequency band of nuclear generated EMP was found effective from 1 KHz to 100 MHz. Since the lethal effect of nuclear burst was the violation of human rights, several non nuclear EMP generating mechanism have been investigated in recent past and a few have also been tried out as weapons in recent wars [Giri, 2004]. It is now well established fact that apart from lightning and nuclear EMP there exists other intense electromagnetic source operating in the frequency range of 200 MHz – 5GHz and can cause upset or damage in electronic systems.

The electromagnetic environment can be classified as:

- * A single pulse (narrow band signal with frequency agility)
- * A burst containing many pulses and each pulse containing many cycles of single frequency.
- * An ultra wide band pulse (100 MHz to several GHz)
- * A burst of many ultra wide band transients

The sources could be spark gap to highly sophisticated EM weapons. The ultimate effect of such EM fields is to create functional loss of a sophisticated analogue / digital electronic or damage permanently the solid-state component of the system. Fig.-1 shows the EM environment.

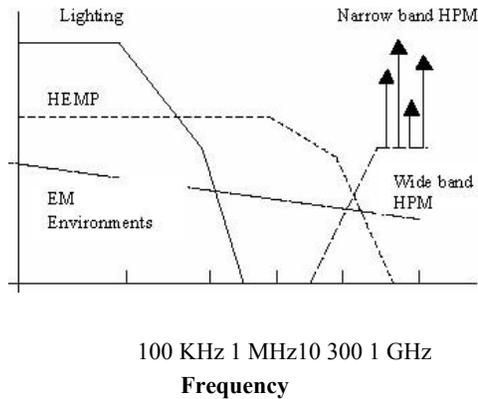


Fig 1- Varying spectral density of EM environmental

This paper discusses, in subsequent sections, the physics of EMP generation, its destructive effect and probable protection mechanism for C³I network.

Physics Of Nuclear Emp Generation

The energy that binds together the components of an atomic nucleus is known as nuclear energy. Part of the binding energy when released due to internal transformations result in the emission of electro magnetic waves or energetic particles. When the nucleus of a heavy element splits into two smaller nuclei, the process is called nuclear fission. When two nuclei of light elements combine to form a larger nucleus, the process is called nuclear fusion. In both fission and fusion, the total mass of original nucleus or nuclei is greater than the total mass of the end products. This lost mass appears in the form of energy, E, according to Einstein's formula:

$$E = m C^2 \text{-----} (1)$$

The energy released per unit mass due to nuclear reaction is million times greater than the energy released due to chemical reaction such as combustion.

A third form of nuclear energy stems from the transformation of an unstable atomic nucleus into a more stable form. Unstable nucleus disintegrates and gives off α particles, β -particles and γ - rays. Prompt γ - rays which follow the nuclear detonation are the principal source of EMP (electromagnetic pulse). Other than these particles a nuclear burst releases fireball of 100 million degree Kelvin, a primary and secondary shock waves called Mach point of thousand pounds or several kilo Pascal (kPa), heat light and harmful nuclear radiation like γ -rays and neutrons.

For the surface, air, and high altitude nuclear burst, the γ - radiation leads to generation of electron flow, due to Compton effect, photoelectric effect and by the pair production effect. The electron flow is radially symmetric and creates a local radial field but not radiated EMP, since no magnetic field can exist for such a case. However, the asymmetry due to proximity of earth, vertical gradients in atmospheric density make the electron flow more vertical creating an electric dipole. This dipole radiates EMP. Quantitatively; the radiated EMP energy from a high altitude burst of a megaton yield is about 10^{11} joules.

The EMP field is governed by Maxwell's two curl equations;

$$E = -\partial B / \partial t \text{ ----- (2)}$$

$$B = \mu j + \mu \epsilon \partial E / \partial t \text{ ----- (3)}$$

where j = current density

μ = permeability of the medium

t = real time

ϵ = permittivity of the medium

The current density, j , is the resultant of driving current and conduction current.

$$j = j_d + \sigma E$$

j_d is driving current

σE is conduction current

further, $j_d = j_c + j_{pe} + j_{pp}$

j_c = Compton current

j_{pe} = photoelectric current

j_{pp} = pair production current

The basic principles of the EMP generation for the high altitude, air and surface bursts are similar but there are characteristic differences in radiated EMP.

High Altitude Bursts

At high altitude (above 30 Km) the atmosphere is thin and allows prompt γ - rays from nuclear burst to travel radially for long distances with a speed of light. Significant deposition region varies with height of burst and weapon size. For 300 Km height of burst and 10 – mega ton weapon the deposition region is as thick as 70 Km (10 Km to 70 Km altitude). Destructive EMP can occur at the earth's surface out to the tangent radius (the line of sight from the burst is tangent with the earth's surface). High altitude EMP is stronger in the frequency band 0.1 MHz to 10 MHz.

Air Burst

Air burst EMP results from a nuclear explosion at an altitude 2 Km to 20 Km. For EMP there is no return path through the ground. The γ -rays travel out radially from the burst and scatter Compton electron radially leaving behind positive ions. The charge separation produces radial electric field. The typical field strength produced is 300 V/m at 5 Km from the burst. The pulse rise time is 1 to 5 μ s.

Surface Burst

A nuclear burst less than 0.2 Km above earth's surface is known as surface burst EMP. The source region is limited to 3 Km to 5 Km. It can affect command centers which are even hardened to withstand thermal energy and shock. The radiated field is harmful away to 10 Km or greater ranges. The lower frequency ranges of EMP are very harmful for large energy collectors like power line that has access to all electrical and electronic equipment and all household gadgets. Conducted EMP can damage these instruments. Surge suppressors only can withstand such high current. If a facility is designed to with stand ionizing radiation and other nuclear effects it should also be designed to with stand the EMP effects The radiated electric fields have amplitude 100 KV per meter with rise time as short as few nanoseconds. Due to

proximity of ground, the strong radial electric field causes a ground current to flow and produces azimuthal magnetic fields. The air-earth boundary also generates strong electric field.

The mechanisms of the generation of the internal EMP, system generated EMP and underground EMP are different.

Internal EMP: It is produced by electron emission from the walls of the system enclosure. They are either Compton electrons or photoelectrons produced due to γ - rays or X-rays or both.

System generated EMP: SGEMP results from the direct interaction of γ - rays or X- rays emitted due to nuclear burst with the system. SGEMP is effective outside the atmosphere where the attenuation is least. Missiles and launch vehicles of the satellite or satellite in space can receive significant γ -rays and X – rays exposures even if sufficient distances separate them. The field amplitude generated can be as large as 100 KV/m.

Underground EMP: When a nuclear explosion occurs underground, the expansion of nuclear explosions and resulting radiation is contained in limited area. But EMP can still be generated by the magneto hydrodynamic effect where the earth's magnetic field is displaced by the products of detonation. It has low amplitude but can damage the interface circuits of long landlines or submarine cables.

Fig.2 shows the peak field intensity of EMP from a high altitude 50 KT burst. The pulse rise time is of the order of 10 ns and the field decays by a factor of 1 / e.

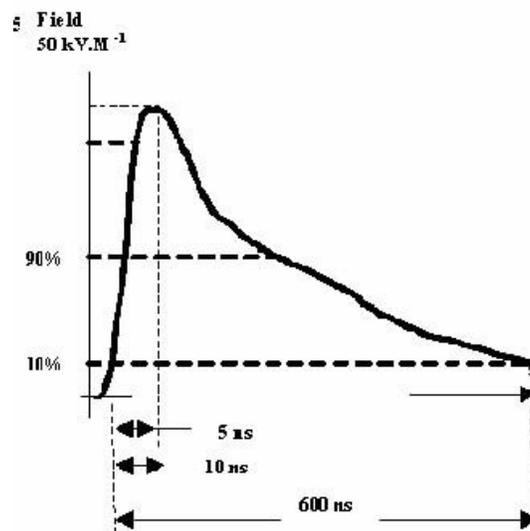


Fig 2- EMP Wave Diagram

The frequency spectrum is shown in Fig. 3. It covers a broad spectrum from ELF to UHF but very effective in the frequency range 1 KHz to 100 MHz.

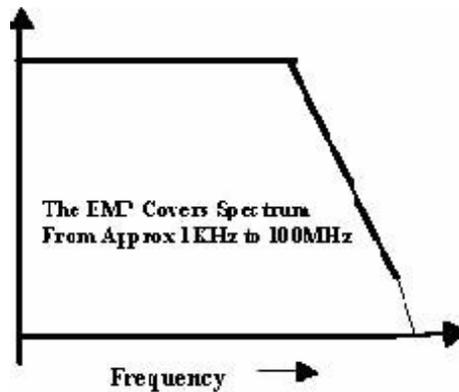


Fig 3- EMP Wave

Non-Nuclear Emp Generators

Non-nuclear EMP generators are non lethal to human but it is capable to destroy the economic infrastructures like; Industries, neutralizes communications, surveillance and targeting systems and could upset or damage all electronic whatever comes under its footprint. As a weapon its role is important in low intensity conflicts and military operations other than war. They are typically narrow band devices, may either be short pulse, high peak power or they may be high average power operating at high repetition rates or in continuous wave (cw) mode. Essentially these sources rely on switching a large amount of electrical energy in as short a time as possible. Such devices are pulsed and use either high voltage solid state or gas breakdown switches. [Barker and Schamiloglu, 2001] The actual rise time of the switch and the length of the pulse determine the characteristics of the radiation sources. These weapons are capable to work in all weather and would be deployed in a covert way since the beam is not visible and the upset or damage could be directed to electronic targets only. These weapons offer military commanders the option of (DDR&E, 1997):

- * Speed of light, all weather attack
- * Area coverage of multiple targets
- * Selected levels of combat
- * Minimum damage in politically sensitive environments
- * Simplified pointing and tracking
- * Deep magazines and low operating cost.

The technical challenges are [Taylor and Giri, 1994]:

- * Compact high power source
- * Compact high gain antennas
- * Compact high power drivers
- * Compact efficient prime power sources

- * Hardening of self induced EM interferences
- * Affordable system integration at military platforms

The conventional electromagnetic pulse weapons are:

- *Explosively Pumped Flux Compression Generators (FCG)
- *Explosive Driven Magneto Hydrodynamic Generators (MHD)
- * HPM devices like Virtual Cathode Oscillators (HPM)

Flux Compression Generators

FCG is a device capable of producing electrical energy of tens of Mega Joules in ten to hundreds of microseconds of time in a relatively small package. The currents produced is thousand times greater than that of lightning stroke. As shown in Fig. 4, fast explosives are used to compress rapidly a magnetic field and transfer much energy from the explosive into the magnetic field. The initial magnetic field prior to explosive initiation is produced by a short current supplied by Marx Generator. The cylindrical configuration is best suited for its application as EMP bomb.

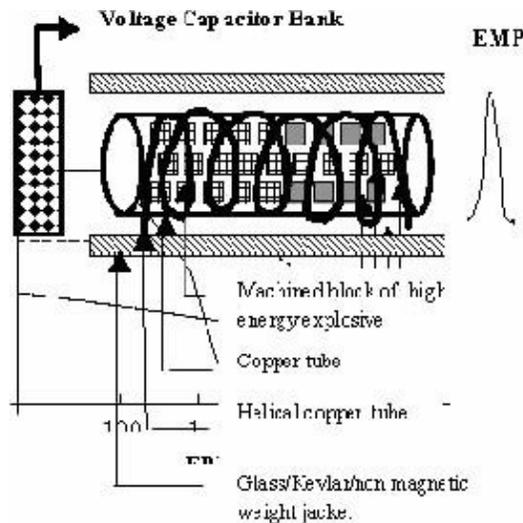


Fig 4- Flux Compressing generator

Magneto hydrodynamic Generators

In MHD an ionized gas or plasma is moving through a magnetic field and produces an electric current transverse to the direction of the field and the conductor motion. The motion causes electric field at right angle. The induced field causes a current to flow as in the armature of a generator. The current is collected by electrodes which are in contact with plasma jet and high power transient is generated by auto switching of electrical circuit Fig. 5. For highly conducting plasma, cesium or potassium is added to the noble gases. To achieve strong magnetic field of 5 to 6 Tesla an iron core copper magnet self excited by part of the generator is preferred.

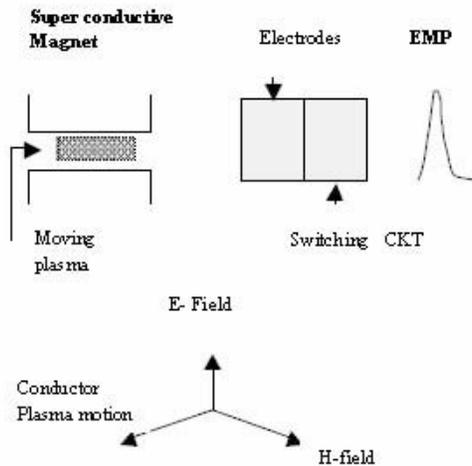


Fig 5- Magneto Hydro-Dynamic generator

The cylindrical configuration is best suited for its application as EMP bomb.

High Power Microwave Devices

In the last two decades there is tremendous development in the power delivery capability of microwave sources. These achievements are largely due to :

- * advances in relativistic electron beam technology
- * gas / oil breakdown research in the nano second time scale
- * studies of solid state switches in the pico second rise time.

The first case led to high voltage (500 KV – 1 MV) narrow band sources, where as the other two improvements resulted in UWB power. Fig. 6.depicts the development of HPM narrowband sources over the past decade.

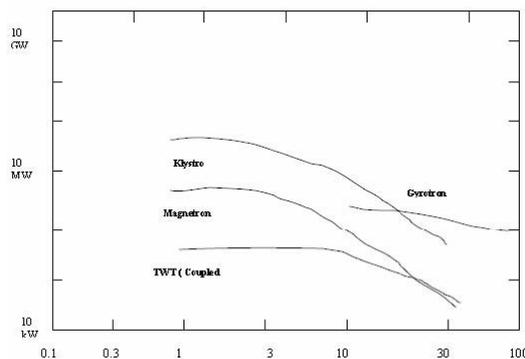


Fig 6- HPM Narrow band sources

Some of the HPM individual sources that have reached high power levels are given in Table – 1.

One aspect of microwave source development that has allowed vast improvements in peak power output is cathode performance. The giga watt (GW) sources have selected the explosive emission cathode because such cathodes “ turn on “ at relatively low electric fields and deliver the very high current densities (100 A / cm^2), hence generates extremely high power. Carbon fiber cathodes impregnated with Cesium iodide (Cs I) have proven to be better choice.

Klystrons, Magnetrons, Slow wave devices, Reflex triodes, Spark gap devices and Vircators are highly matured technologies. With to days approved and matured HPM devices it is possible to generate energies greater than $270 \mu \text{ J / m}^2$ with 100 n s pulse width at a distance 30 Km from the source. The technologies in offing can increase the fluency level by a factor of 10^4 that may affect even biological targets at larger distances. Vircator is one-shot device capable of producing very powerful single pulse of radiation. It is mechanically simple, small, and robust and can operate relatively over a broad band of microwave frequencies.

TABLE 1

Power	Freq	Tunable	Pulse	Energy
1GW	400-800MHz	Yes	75-125ns	100J
400 MW	325-407 MHz	Yes	<140ns	<56J
400 MW	435-544 MHz	Yes	<140ns	<56J
400 MW	660-820 MHz	Yes	<140 ns	<56J
15 GW	1.3GHz	No	90ns	1350J
3GW	1.1GHz	No	80ns	240J
2GW	1.3GHz	No	200ns	400J
1.5 GW	1.3GHz	No	120ns	180J
1GW	0.8-2GHz	Yes	75-125ns	100J
1.6 GW	2.4GHz	No	30ns	50J
1GW	3.5GHz	No	180ns	180J
1GW	2-4GHz	Yes	75-125ns	100J
800 MW	2.8GHz	-18%	40ns	30J
1GW	4-8GHz	Yes	25-75ns	75J
320 MW	5.5GHz	-11%	80ns	25J
1GW	8-10GHz	Yes	25-75ns	75J
800 MW	9.4GHz	-2%	15ns	12J
500 MW	10GHz	-20%	100ns	50J
300MW	8.5GHz	No	10ns	3J
260 MW	8.2GHz	No	5-15ns	4J
150 MW	3GHz	No	3000ns	45J
50 MW	11GHz	No	2500ns	125J
20	1GHz	No	50ns	<1000J

Destructive Effect Of Emp

The million joules of EM energy when impinges on or coupled to electronic equipment / systems / sub systems the devices suffer permanent damage or gets disabled temporarily.

Devices vulnerable to EMP effects are:

- * Radar
- * Electronic warfare equipment
- * ELF, VLF, HF, VHF, UHF, SHF, EHF Communication Equipment
- * Computer / Data processor
- * Electronic Flight Controller
- * All digital electronics. etc.

Modern electronic equipment uses MOS / CMOS devices which are very sensitive to high voltage pulse transients. Semiconductor junction is vulnerable to thermal damage and electrical breakdown. The pulsed power failure satisfies the equation:

$P = A t^{-B} W$ where, A and B are constants t = pulse width in seconds

The primary concern is the prevention of permanent damage in semiconductor devices. Latch up prevention can be achieved by latch up screening of all susceptible devices. IC electrical time constant

and time constant of associated RLC circuitry can control transient recovery time of a linear IC.

The interaction of the electromagnetic wave with the system is a system level interaction. The modes of electromagnetic pulse entry is discussed below:

Diffusion Through The Shield

Electromagnetic pulse diffuse through imperfectly conducting walls of shielded enclosure. The diffusion is greatest for magnetic fields and is a low pass filtering effect. The surface irregularities on the wall polarize static electric current, which induces electric field inside the chamber. This effect can be greatly reduced by double wall with dielectric separation i.e. 1.6 mm thick MS or Aluminum sheet separated by an inch where poly urethane foam (PUF) is compressed with a pressure of 2.4 Kg per cubic cm. The welded enclosure provides sufficient shielding effectiveness of the order of greater than 80 dB.

Leakage Through Apertures

Openings like doors, windows, utility lines / holes, improperly terminated cable shields and poorly grounded cables can couple EMP energy directly in to the shielded enclosure. Leakage through an aperture depends on its size, the type of structure housing it and its location. The aperture responds to both electric and magnetic field. To protect EMP entry beryllium / copper

fingers, conducted gaskets, gas arresters and proper grounding mechanism is used at appropriate places.

Coupling Through Antenna

Antennas are meant for operating at desired frequency band. However, there will also be an out of band frequency response of an antenna. Since the impinging EMP field has a broad frequency spectrum and high field strength, the antenna response must be considered both in and out of band. Inadvertent antennas are, electrically penetrating conducting structures, power lines, communication cables and AC pipes that collect EMP energy and allow its entry into the enclosure. Power line filters, communication line, telephone line, and data line filters with proper shielding protect EMP entry.

Conductive Penetration

Many factors affect the coupling of EM energy to penetrating conductors. The EMP waveform characteristics, such as magnitude, rate of rise, duration and frequency are each important. Observer's position with respect to NEMP or Non NEMP burst is an important factor. The interaction between fields and conductors is a vector process. Conductor geometry like; length, path, terminations, distance above or below earth surface, physical and electrical properties which determine series impedance per unit length and the presence of shielding effectiveness are the key parameters to be considered.

Principles Of Emp Coupling

The basic principle behind coupling of current and voltages with conductors are the process of induction. The impinging electric field exerts forces on the mobile electrons in the conductor that result in a current. The voltage associated with the force is the integral of the tangential component of E along the length of the wire. This is based on the assumption that the electric field is constant over the length of conductor wire and is parallel to it. The other mechanism is when the current is induced on the conductor through changes in magnetic field. Faraday's law relates the time rate of change of magnetic field to the corresponding produced electric field.

Hardening Approach For C³I Facility

A shielded enclosure welded at all seams and joints attenuate the impinging EMP field usually up to 80 - 100 dB depending on thickness and surface uniformity to provide low impedance path to surge currents with optimum grounding. All conductive utility lines are circumferentially welded to the shield and PVC or other non-conductive lines are used wherever feasible. Telephone lines are fiber optic or filtered. Power lines and antenna lead ins must be filtered preferably with surge arresters to protect the more expensive filters. The shield is provided with grounded grid to ensure a good path to ground. Air conditioning vents and ducts are provided with honeycomb filters. The computers are required further separate shielded enclosure to attenuate the EMP energy to a tolerance limit. Wherever possible only mil grade and industrial grade component is to be used in sub system / system development. The electromagnetic compliance is preamble to EMP hardening but does not guarantee system survivality. Therefore, all protection methods are needed to be used appropriately.

Conclusions

Critical facilities like command, control, communication and intelligence networks are the prime target in the modern war. The combat operations always target this location and facilities as they have equipment that processes classified information. EMP a bi – product of nuclear burst or EMP released due to non-nuclear sources are capable to damage C³I network. It is critical to national security; therefore, require EMP protection measures to prevent compromise of information and disastrous damage to electronic equipment.

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