ELECTROMAGNETIC PULSE (EMP)

BACKGROUND

The EMP or "radio flash" effect is the name applied to an electromagnetic disturbance generated by a nuclear detonation, however, EMP effects have been observed in high explosive as well as nuclear detonations. Theoretical physicists predicted EMP during the development phases of nuclear weapons. EMP protection was provided for test instrumentation and a number of EMP measurements were made during the various nuclear tests. During the Fish-bowl series of tests in 1963, effects were recorded in widely separated locations indicating that EMP from high altitude detonations could pose serious problems for unprotected communications and power networks. Star Fish, a 1.4 megaton detonation at 400 kilometers altitude, caused a number of outages and other disturbances as far away as Honolulu.

The primary interest at that time, however, was focussed on other nuclear effects, such as blast, thermal, and electromagnetic blackout. Although EMP was recognized as a possible threat it was not widely understood. After many years of research involving the improvement of EMP theory, the analysis of nuclear test data, the design of large computer codes to calculate EMP effects, and the development of EMP simulators which can demonstrate the effects of EMP, the seriousness of the problem has been generally recognized. As a result a number of military defense systems which must operate in a nuclear environment have been hardened against the effects of EMP. EMP protection criteria and specifications are being included in design and test requirements for new systems, and existing systems are being assessed and upgraded as needed. These systems include aircraft, missiles, satellites, a wide variety of ground based communication systems, and some power systems.

The details of EMP phenomenology and effects are largely documented in a number of classified handbooks and source documents which cannot be cited here. These contain comprehensive and up to date information on the subject and should be consulted if possible. Recently, a document (reference 1) was published in the open literature by the Defense Nuclear Agency which is much more thorough than the simple treatment we have provided here and is recommended to the reader for further study of EMP considerations.

EMP ENVIRONMENTS

The electromagnetic pulse following a nuclear detonation produces intense transient electric and magnetic fields with very short rise times and a frequency spectrum extending from almost zero to more than 100 MHz. Basically, the environments can be divided into 3 types–ground-burst EMP, air-burst EMP and high-altitude EMP. Ground-burst EMP includes bursts on or near the surface, i.e. below approximately 0.3km, air-burst EMP includes bursts from between approximately 0.3 and 40km; and high altitude covers bursts above about 40 km. Figure 1 depicts the different types of bursts and the area of intense electromagnetic fields produced by each.

Bursts on the ground and within the atmosphere produce intense fields in the source region, or deposition region, but this region covers a relatively small area. High-altitude bursts, on the other hand, can produce significant fields over wide geographical areas and probably pose the greatest EMP threat to susceptible systems. It should be noted that all bursts radiate signals which can be detected at great distances.

GENERATION MECHANISMS

The primary source of EMP is gamma radiation. Gamma rays are high-energy photons, emitted directly from the fission process in an exploding nuclear bomb. These photons are also emitted by the interaction of neutrons from the bomb with the air or ground near the burst point. About 0.1% of the energy of a typical nuclear bomb appears as prompt gamma rays. As the stream of high-energy photons moves through the Air Compton* scattering collisions occur and a current of appproximately one-MeV electrons is produced. It is this electron current which is the direct cause of EMP.

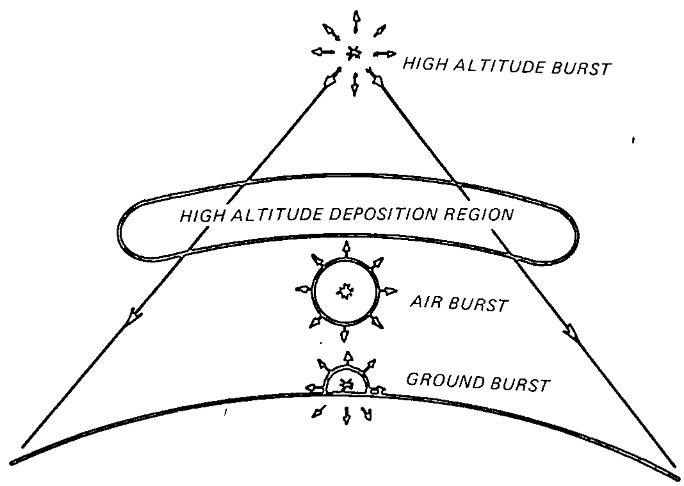

Figure 1: Simple Comparison of EMP Regions

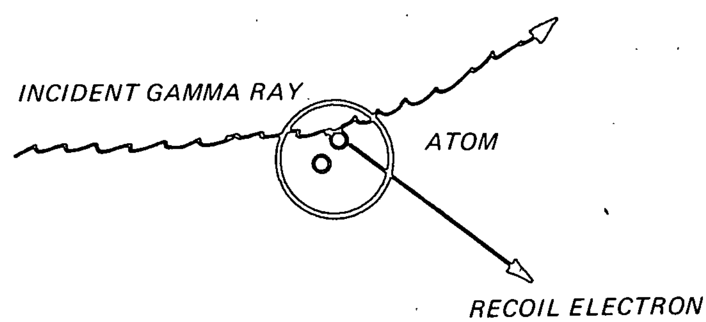

Figure 2: The Compton Effect

The Compton scattering phenomenon, depicted in Figure 2, is a process in which a gamma ray collides with an electron (e.g. in an oxygen or nitrogen atom) and propels it in or near the forward direction of the original gamma ray. This process is repeated for each of the prompt gamma rays in a very short period of time. The large number of outward-steaming Compton recoil electrons constitutes an electric current, called the Compton current. This current gives rise to electric and magnetic fields.

Compton electrons, in passing through the air, free large numbers of low-energy secondary electrons from atoms by ionizing (or Coulomb) collisions. These low-energy electrons strongly enhance the electrical conductivity of the air. Thus the electric field, generated by the Compton current, in turn produces a conduction current in the air. The conduction current generally tends to eventually cancel the Compton current, and to limit the EMP generated.

If a spherically symmetric bomb were exploded in a uniform atmosphere, only a radial electric field would be generated, which would exist only in the vicinity of the burst point, and electromagnetic waves would not be radiated large distances. Realistically, however, asymmetries in the bomb and its environment lead to the production of dipole electric and magnetic fields and to electromagnetic waves which propagate large distances. The chief environmental asymmetries are the

**In 1924 a physicist, A.H. Compton, discovered that the collision of photons with electrons can dislodge the electrons from their atomic bonds.*

air-ground interface for low altitude bursts no more than a few kilometers above the ground, and the air density gradient and the earth's geomagnetic field for bursts at higher altitudes. For burst altitudes above 40 km the earth's geomagnetic field creates a very strong asymmetrical force on the Compton electrons. In the reduced density of the atmosphere at around 30 km this force deflects the radial Compton electrons, and therefore current, into transverse directions, and the transverse currents radiate as if propagated from a well-designed antenna.

Although gamma radiation is the primary source of EMP generation, it should also be mentioned for completeness that X-rays may also give rise to EMP through their photo-electron production. Even the intense plasma bubble created in air by a nuclear detonation may be responsible for generating EMP by temporarily excluding the earth's magnetic field from the burst region.

Ground–Burst EMP. When a nuclear detonation occurs at the earth's surface, gamma rays and the resulting Compton current flow approximately radially from the burst point. The initial result of the radial Compton current is a radial electric field caused by the separation of positive and negative charges. In the air, at distances less than two kilometers, this radial electric field builds up until it drives a conduction current which balances the Compton current. At these short distances the radial electric field saturates and increases no further. The peak value of the saturated radial electric field is thousands of volts/meter with a very short rise time.

The gamma rays and the Compton electrons penetrate only a few feet into the earth. However, due to the relatively high conductivity of the earth, the radial electric field in the air just above the earth is disturbed and the conduction current near the earth tends to flow in the ground. This sets up current loops, with Compton electrons flowing outward from the detonation in the air and conduction currents flowing forward to the burst point in the ground. These current loops produce an eximuthal magnetic field, strongest at the Earth's surface but diffused by the skin effect into the air and the ground. The peak value of the magnetic field can be on the order of 100 gauss with a very short rise time. Both fields, the radial electric field and the azimuthal magnetic field, decay in a short time, on the order of microseconds.

In the air, the vertical and transverse dipole electric fields decay much more slowly and maintain values of many volts per meter for a long time. However, the power that can be delivered by these fields is limited by the increasing resistivity of the air caused by the attachment of electrons and the recombination of ions.

The field descriptions given thus far apply to the source region (deposition region) within a few kilometers from the burst, where the Compton current and conductivity are important. At greater distances the latter effects are neglible; the electric and magnetic fields at these distances propagate as waves generated in the source region and fall off as the reciprocal of the distance. This is due to the air-ground interface which allows only upward Compton current, and produces an electric dipole signal for distant observers.

Air-Burst EMP. At higher burst altitudes, there is a decrease in the azimuthal magnetic field, the transverse electric field and long distance field radiation. The radial electric field does not depend upon the ground for its existence. As the burst point is moved upwards, there is at first an increase in the radius of the region inside which an intense radial electric field is produced due to a decrease in attenuation of the gamma rays by the air. This holds to altitudes at which there is not enough air to make a strong Compton or conductions current, whereupon the radius of the intense electric field region decreases.

Air bursts produce some radiated fields due to the earth's geomagnetic field and air density gradient asymmetries, but they are generally smaller than for ground bursts and much smaller than for the radiated fields from high-altitude bursts.

High-Altitude EMP. The gamma rays from high-altitude bursts travel outward in all directions. Because of the extremely low air density, there is little attenuation of the horizontal and upward rays. However, the gamma rays that travel downward toward the earth eventually encounter the denser atmosphere and produce Compton recoil electrons. At an altitude of approximately 30 km the gamma ray attenuation length becomes equal to the atmospheric scale height. This is the source (deposition) region for high altitude EMP.

The Compton Current from a high altitude burst is initially directed downward, but is soon deflected by the earth's geomagnetic field and a transverse current results. The transverse current generates a radiated EMP which continues to propagate downward radially from the burst point and is also partially reflected by the ground. Objects in and below the source region are exposed to this pulse. The EMP from high-altitude bursts covers large geographical areas. An area of coverage of 1200 miles radius for a detonation at 300 kilometers is cited in Reference 1.

Although the actual EMP threats are classified, some of the basic characteristics of a representative EMP from a high-altitude burst have been published in unclassified literature. Reference 2 gives the following:

"A representative electromagnetic pulse from a high-altitude burst will typically have maximum field strengths near the ground on the order of 50kV/meter, time duration on the order of a microsecond and rise times on the order of 10 nanoseconds, resulting in broad frequency effects to systems and equipments and dampened exponential ringing of circuits at their fundamental and harmonic frequencies."

More information, including plots of electric field time wave forms and calculations of representative induced transients, can be found in References 3 and 4.

SYSTEM DEFINITIONS

Unfortunately for the engineer concerned with designing protection for critical circuit elements, an understanding of the EMP environment is only part of the knowledge needed. The transient current or voltage waveform seen by a specific transistor or integrated circuit may bear little resemblence to the shape of the incident EMP waveform discussed previously. This is due to the fact that the response of the overall system determines the coupling between the incident EMP and some particular circuit element.

As an example of system effects, consider a missile in flight. Assume the missile is illuminated by the EMP from a high-altitude burst sufficiently far away so that blast and radiation effects can be ignored. If the outer skin of the missile is a perfect conductor with no holes or penetrations, it will serve as a Faraday cage and no transient will penetrate to circuits within the missile. The incident field, however, would induce currents on the skin of the missile. A long, thin missile would look much like a dipole antenna and thus the skin currents would tend to flow back and forth on the missile at some resonant frequency determined by its length. These skin currents eventually re-radiate the induced energy so that the skin current waveform resembles a damped sinusoid. Note that both the frequency and decay time of such a damped sinusoid are functions of the shape of the missile rather than that of the incident EMP waveform. The magnitude of the incident field in the frequency band of interest is important, however, in determining the magnitude of the induced skin current.

Now consider a more realistic missile with numerous apertures, antenna feed-throughs, hatches, and other deliberate penetrations in its metal skin. The skin current will resonate about the same as it would without the penetrations, but all the "holes" in the metal shield will allow various amounts of energy to couple into the missile. The fields that penetrate the skin often have waveforms characterized by the dominant resonance of the induced skin currents. However, the waveform may well be changed again due to the nature of the penetration. A cavity within the missile may be excited and ring at its primary resonant frequency, or an actual antenna may change the shape of the waveform by responding to certain frequencies better than to others. By the time the transient reaches some critical circuit component, its waveform and energy content will be considerably different from that of the incident EMP.

Hence, the design engineer is forced to think in terms of overall system response to EMP rather than considering simply a specific incident EMP signal driving the particular circuit of interest. The overall system response can be very complicated. Theoretical calculations are extremely difficult due to system complexity, and experimental tests are often extremely expensive, if possible at all, on large weapon systems. However, some simple means for characterizing types of systems and their responses can be very useful in understanding the overall problem.

One possible way to characterize a weapon system is to use the system's location and expected operational environment. From these the design engineer can postulate the nuclear effects the system may be required to withstand.

Satellite Systems. The primary EMP threat to a satellite can come from either of two sources. The first is the radiated EMP from a distant burst. If this signal travels through the ionosphere, dispersion effects will greatly change the shape of the incident waveform, eliminating the lower frequencies and dispersing the higher frequencies. A second threat is due to what is known as system-generated or internal EMP. If a nearby nuclear burst illuminates the satellite with numerous x-rays and gamma rays, the photons produce Compton electrons and photoelectrons, which in turn produce large electromagnetic fields.

Missile Systems. The EMP threat to a missile depends greatly on the location of the missile. A missile underground in a hardened silo is obviously a different problem than that of a warhead approaching its target. In its silo, the missile system includes all the associated ground equipment, power supplies, communication links, and control equipment. Nearby ground bursts may be expected, hence planning must take into account blast, shock, and radiation effects as well as EMP. After launch and during powered flight, the ground equipment is no longer part of the system and the shielding effects of the silo are no longer present. After engine burnout, the delicate electronics of the guidance computer may no longer be of importance, but the warhead fusing mechanism obviously is of prime importance. The characteristics, and consequent protection problems, of such a system change as the mission progresses.

Aircraft Systems. One may question the need to protect aircraft from EMP effects since many aircraft have flown in the vicinity of nuclear tests without apparent damage. Nevertheless, a potential EMP problem exists due to the increasing use of sophisticated electronics in aircraft, including computer directed navigation and weapon delivery systems. The prime EMP threat to aircraft is the high-altitude burst, simply because at the limited range of EMP effects at low altitude the other nuclear effects become much more important.

Ground Systems. The term "ground system" is very broad and covers a diversity of military hardware including ships, tanks, large radars, satellite tracking stations, etc. Any of these systems may contain electronic equipment requiring protection from EMP. Radars are designed to be extremely sensitive receivers of electromagnetic radiation. Telephone switching centers, highly important for effective command and control, are connected to long lines which tend to collect and focus EMP energy. Computer facilities may be upset by transients induced in power lines. In all, it seems that a great number of circuits need protection against EMP-induced transients.

The main reason for briefly reviewing these various categories of military systems is to point out the vast diversity of devices requiring EMP protection and to note that the problems of each of these systems may be completely different. An unshielded radar obviously has problems different from those of a missile sitting in a concrete and steel enclosed silo. A designer working on EMP protection must consider the overall system with which he is working.

COUPLING MODES

External Coupling

As in the example of a missile in flight, it is sometimes convenient to divide the EMP coupling problem into a series of steps proceeding from the incident signal toward the particular circuit or component of interest. The first step in this sequence is frequently called "external coupling".

External coupling may be viewed as the overall response of the system to the incident fields. In the missile example, external coupling would refer to the skin current and charge density induced on the conducting skin of the missile by the incident EMP. For an aircraft, information on the induced current in wings, fuselage, tail and other exterior surfaces would be the goal of external coupling analysis or experiments. For a radar, external coupling analysis considers the effect of the incident EMP signal on the antenna. The concept of external coupling is to attempt to simplify the problem by finding some overall response of the system. This overall response is usually characterized by certain gross electromagnetic features of the system such as the dimensions and shapes of the principal conducting surfaces; e.g., the skin of a missile. In many cases these conducting surfaces form at least a partial shield around various electronic packages and are thus the external parts of the system that first "see" the EMP. It is also known experimentally that waveforms measured deep inside a system may have dominant frequencies that are determined by the prime resonances of the external structure. Thus an understanding of external coupling is necessary in determining what goes on inside.

One should note that it is sometimes difficult to decide what is the "external" part of a system. For example, a missile or aircraft may have fiberglass rather than a metal as its skin. In such cases, the interior electronics are illuminated directly by the incident EMP because the external surface offers essentially no shielding.

Internal Coupling

The next step is this coupling sequence is labeled "internal coupling." Here the analyst is concerned with how the transient energy gets from the outside to the inside of the system because no metal skin or shield is ever really continuous. Small holes, faulty RF seals, windows, and deliberate penetrations for signal cables, power lines, water pipes, etc., always are present and allow some transient fields to leak into the system. Once the energy enters, coupling take place in a variety of ways. On an aircraft, the incident EMP fields may leak through the doors of the bomb bay into a cavity (the bomb bay) that resonates at the cavity-size-dependent frequency. Hundreds of cables may run through the bomb bay and currents induced on these cables may be carried throughout the aircraft to critical components. The coupling analysis is thus complicated because of the complexity of the system, and standard circuit analysis techniques are difficult to apply since the various fields form a distributed source which drives the entire circuit all at once.

HARDENING TECHNIQUES

Tracing the path of the EMP signal finally leads to some critical circuit element where the induced current or voltage waveform will cause transient upset or even actual physical damage to the component. For example, the EMP induced transient may reset a flip-flop of a digital circuit in a computer or control device resulting in a missile missing its target. Enough energy might be deposited in the junction of a transistor or integrated circuit to cause burn out or changes in operating characteristics. Another possibility is the inadvertent shorting out of a power supply due to arcing and insulation breakdown in its connectors and cables. Thus, it can readily be seen that a large number of devices may require some EMP protection.

Although it is virtually impossible to eliminate all the transients induced by an electromagnetic pulse, certain general design guidelines can be used to greatly reduce the amount of energy reaching the most critical circuit elements. These guidelines can be used to "harden" the system to EMP effects so that there will be less chance of logic upset or component damage. Because these hardening techniques are highly dependent on the properties of the overall system, they are best applied when the system is first designed. Hardening a soft system can be very expensive. In this section we discuss certain general principles including circuit layout, shielding, grounding, and cabling. Specific protective devices are covered in later sections.

Shielding

Deliberate electromagnetic shielding is probably the best way to harden a military system against EMP effects. Screen rooms can be built to attenuate fields by several hundred db, but military systems cannot always be placed inside shielded enclosures. Aircraft must have doors, windows, and a myriad of ports and hatches as well as external antennas. Also, the airframe weight must be as low as possible for maximum payload and performance. Thus it is readily apparent that in real life conflicting requirements often result in compromises in any electromagnetic shielding system.

Many analytical and experimental studies have been directed at understanding shielding and the penetration of electromagnetic fields through imperfect shields. Here we discuss only the general idea of what makes shielding imperfect; i.e., how energy penetrates practical shields and how these penetrations are minimized. Perhaps the most obvious fact is that no real shield is perfect. Numerous "holes" or penetrations, both deliberate and accidental will exist in any metal shield. Joints in metal skins are often built for mechanical integrity rather than electrical continuity, access doors or windows may not be fully closed, and RF gaskets may become worn or faulty. Rubber seals may resist gas pressure but pass EM radiation. Fiberglass or other non-conductors may be used for surface panels in situations where the electrical effects are considered less important than other factors. Or the skin may be simply so thin that it offers little protection against low-frequency signals (particularly the magnetic field).

Deliberate penetrations include a variety of antenna feed-throughs, communication lines, or power distribution systems–all deisgned to couple specific types of energies into the shielded enclosure. An example of the problems posed by such penetrations is the out-of-band response of an antenna. Often not even considered by the antenna designer, this characteristic may provide transparency in the frequency regime of the prime energy band of the incident EMP and thus may result in the direct coupling of damaging energy to delicate receiver electronics.

Mechanical considerations provide another class of deliberate penetrations, for example water pipes and sewer lines. To EMP, such penetrations may well appear as very good antennas leading directly through the shield. The designer must consider the electrical implications of each such penetration as carefully as he considers mechanical efficiency.

A conducting cage with a minimal number of penetrations surrounding the system being protected can provide adequate shielding. This shielding can be added specifically to protect against EMP, or the existing structure with a few modifications can be used as a shield wall. Multiple shields, one inside the other, can be used with great effectiveness. However, no shield is really "perfect" and the engineer should always be alert in order to detect and eliminate as many unnecessary penetrations as possible.

Cabling

Since long lengths of cable will act as efficient antennas for receiving EMP, it is fairly obvious that the use of properly designed and shielded cables will add protection to a system. Shielded cables are better than unshielded, tightly braided shields are preferable to loosely woven ones, and solid shields are the best of all. Unfortunately, cable costs may rise dramatically as the shielding quality increases.

Some cables require shielding for reasons other than EMP protection. Cables carrying high frequency signals are often shielded to prevent pickup of RF noise from other sources. Such cables are probably "hard" to EMP damage. On the other hand a vast number of power line and low frequency communication links use cables with little or no shielding and all such cables should be considered antennas when considering the EMP response of a system. Also, a typical problem with shielded cables is the use of improper connections at the cable ends. If they are not fastened properly initially, or work loose with use, they may allow energy to couple to the inner conductors, rather than harmlessly draining through the shield.

Grounding

Traditional ideas about grounding must be carefully considered when applied as techniques for hardening systems to EMP damage. For instance, the concept of driving a metal stake into the earth and running a connecting wire from the stake to the grounded end of a circuit may be of no value at all with respect to EMP protection. At the high frequencies seen in an EMP, the connection between the stake and the earth is a high impedance. In addition, the connecting ground wire may actually couple energy *to* the circuit rather than *away* from it.

More complicated grounding schemes may be useful, but even well-designed grounding systems for lightning protection may be useless for EMP purposes because the EMP signal contains higher frequency components. In addition, differences in the electrical parameters of different kinds of soil make general purpose grounding schemes difficult. Internal grounds that provide a common reference potential for a variety of circuits are a somewhat different story. Such grounds may be somewhat useful if the connecting wires do not form ground loops or act as receiving antennas for the EMP.

Protection Devices

In tracing the EMP energy from its source (a nuclear burst) to some critical circuit element it was noted that in the last step of the coupling process the EMP is characterized at a given point by some voltage transient with a given source impledance (i.e. energy content). The system can be hardened by introducing a protection device to eliminate or at least change the nature of this waveform before it reaches critical circuit elements. These protection devices are a class of circuit elements designed to reduce the effects of transients on the normal operation of the circuit. Included under the category of protective devices are: various filters and chokes, fuses and circuit breakers, silicon controlled rectifiers (SCR's), zener and other diodes, spark gaps, gas tubes, transformers, non-linear resistors, as well as many hybrid designs combining several of these concepts.

The important differences between devices depend on such things as response time, allowable transient voltage or current levels, and energy absorption capacity. For example, solid state diodes may react very quickly but their junctions may burn out if they receive large amounts of energy. A fuse, on the other hand, is rather slow to act and actually requires a fairly large amount of energy to work at all. Due to these varying characteristics, no one device is best for all applications and the engineer must make an intelligent evaluation of the specific case in question in order to choose the proper protection scheme.

References

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The material used in this article was taken, with permission, from a booklet entitled "A Guide to the Use of Spark Gaps for Electromagnetic Pulse (EMP) Protection". Copies of this 80 page booklet are available from Joslyn Electronic Systems, Federal Products Dept., P.O. Box 817, Goleta, Ca. 93017

SUPPRESSING CONDUCTED EMP TRANSIENTS

EMP POWER & SPECTRUM

EMP pulses are characterized not only by high intensity but also by a broad range in the electromagnetic spectrum. RF energy produced in nuclear blasts span the range from commercial radio up through radar frequencies. This peaks out at about 100kHz and drops off substantially at 1GHz as shown in Figure 1.[2] Most military and commercial communication and radar equipment operate within this range.

Some components, such as vacuum tubes, resistors and capacitors, are relatively hard. However, semiconductors are quite sensitive to the fast electrical pulses generated by EMP. Burn-out levels for transistors, diodes, and ICs cover a broad range. Minimum observed energy levels to cause destructive effects occur as low as 10^{-7} joules for microwave diodes up to 10^{-1} joules for some audio transistors. Contrary to logical thinking, steady state power dissipation may not be indicative of ability to withstand fast rise-time, short duration EMP pulses. For example, a 30 joule rated varistor was destroyed with a 10^{-4} joule pulse from a simulated EMP source.[3] A 50 watt steady state rated zener diode can burn out with a pulse of 10^{-2} joules and a 10 watt steady state rated zener diode can burn out with a pulse of 5×10^{-3} joules.

For purposes of establishing a frame of reference, lightning has been compared with EMP, largely because of the historical information gathered in the study of meteoric electricity and its effects on electronic equipment. Although lightning strokes are fast, 5 to 10 microseconds to crest, the transient voltage pulses induced into cables struck by a lightning discharge are stretched up to an order of magnitude or more. This transformation occurs because of the line inductance, end (termination) capacity, and the fact that lightning has a definite source of feed point. However, it is doubtful whether currents from distributive sources, such as EMP (or far-field lightning), would be stretched when conducted along cables.[4] Because of this difference, along with the high frequency energy present in an EMP, entirely new techniques must be considered when protecting against EMP exposure.

EFFECT OF CIRCUIT INDUCTANCE

Because of the fast rise-times of EMP, of the order of 5,000V/nanosecond and faster, inductive effects which generate voltage spikes described by the relationship

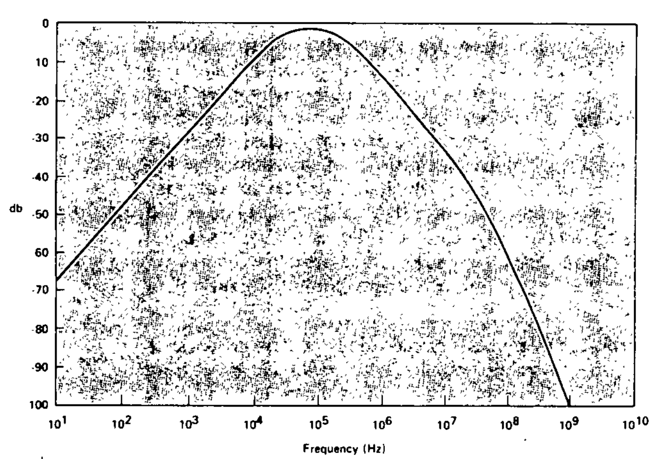
$$V = L\frac{di}{dt}$$

can be very significant. That which may appear to be negligible inductance, can be the source of voltage surges which can destroy sensitive components. Excessive lead lengths in transient suppression devices may very well be the source of destructive effects from which the device was inserted to give protection! The magnitude of "overshoot" voltage, or pulse energy leakage, due to length of device interconnecting leads is graphically illustrated in the following controlled series of tests.

TransZorbTM* silicon transient voltage suppressors were used in these experiments because of their fast "sub-nanosecond" response characteristics. The oscillogram in Figure 2 shows the open circuit voltage 5kV test pulse impressed upon the devices in subsequent surge tests and the oscillogram in Figure 3 depicts the 100A current pulse for the device under test. Because of the extremely low impedance of the suppressor under avalanche conditions, of the order of 50 milliohms, all devices in subsequent tests yielded approximately the same readout, approximately 100A, for current through the device. Suppressors of the 30V type, with varying lead lengths, were used to illustrate the effects of inductance in a transient suppression circuit.

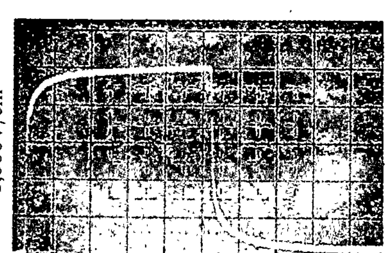
Figure 4 depicts the overshoot (pulse) voltage produced under a 5kV pulse by a 30V silicon avalanche transient suppressor having 3 inch leads on each end. The magnitude of the voltage spike generated by the inductance in the leads is about 1200V peak and 20 nanoseconds in length.

*TransZorb–Trademark of General Semiconductor Industries, Inc.



Normalized Power Spectrum of EMP
Figure 1

1,000V/cm

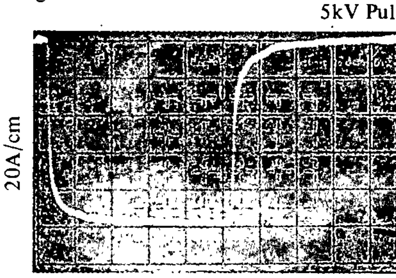


50ns/cm

Figure 2–Voltage Test Pulse

5kV Pulse

20A/cm

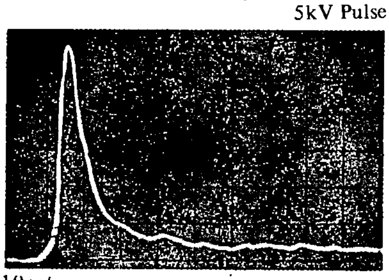


50ns/cm

Figure 3–Current Pulse Under Test Load

5kV Pulse

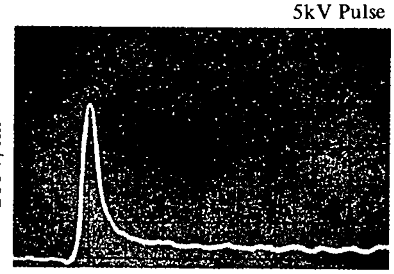
200V/cm



10ns/cm **Figure 4**

5kV Pulse

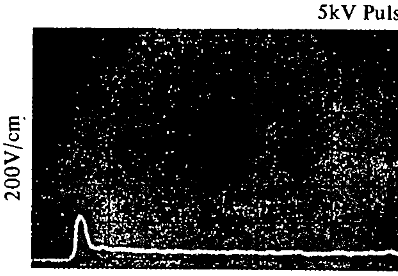
200V/cm



10ns/cm **Figure 5**

5kV Pulse

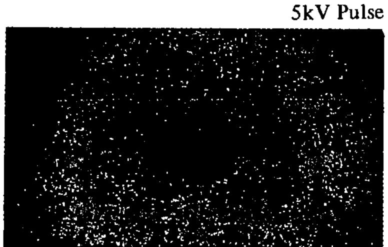
200V/cm



10ns/cm **Figure 6**

5kV Pulse

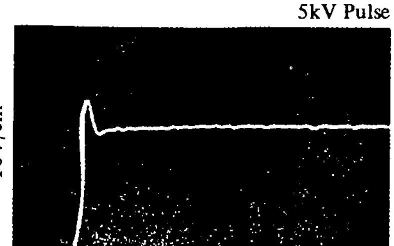
200V/cm



10ns/cm **Figure 7**

5kV Pulse

10V/cm



10ns/cm **Figure 8**

The energy of this pulse produced in the protective circuit using the relationship

$$E = \int P\,dt$$

is calculated to be 1.5×10^{-4} joules. An EMP pulse of this magnitude will burn out FETs and some types of switching transistors.

The next oscillogram (Figure 5) shows the overshoot of the same device also under a 5kV pulse except with 1¼ inch leads at each end. Reduction in lead length brings about a reduction in the inductive voltage spike. The voltage overshoot for this device is about 800V with a pulse width of 10 nanoseconds. Energy produced by this pulse is calculated to be 7×10^{-5} joules. EMP pulses of this magnitude will burn out FETs, microwave diodes and germanium diodes.

In Figure 6, the same device is shown except it is terminated at the package and is virtually leadless externally.

When the external lead lengths are reduced to zero, there is yet a measurable overshoot voltage contributed by inductance of the lead wires within the package itself. The energy produced by this inductance under a 5kV pulse is calculated to be 6.7×10^{-7} joules. This is sufficient to cause burn-out of microwave diodes.

By modifying the device package into a disc and removing virtually all of the inductance from within the package and simultaneously reducing inductance of the insertion method, the inductive overshoot is reduced even farther as shown in Figure 7.

The amount of energy leakage with a 5kV pulse is unresolvable from the oscillogram made with the same vertical sensitivity as for the previous tests. Figure 8 depicts the same device and conditions as Figure 7 except the vertical sensitivity has been reduced from 200V/cm to 10V/cm.

Energy leakage through this system above the clamping voltage is calculated to be 1.5×10^{-9} joules. This is below the threshold of destruction for semiconductor devices.

EMP SUPPRESSION USING TRANSZORBS

Early studies performed under the direction of the U.S. Army Mobility Equipment Research and Development Center proved the feasibility of using silicon avalanche devices for EMP suppression.[5] This work incorporated the use of standard TransZorb product in the 1.5K6.8A through 1.5K200A series which are relatively new transient protectors on the market. These devices are characterized by small size and high transient power handling capability which is 1,500 watts for 1 millisecond up to 100,000 watts for 100 nanoseconds. Protection voltages available range from 5V through 200V for the standard product. Devices can be stacked in series to yield higher voltages as required. For higher power dissipation, devices can also be stacked in series or parallel depending on the design required.

Clamping of EMP is achieved through avalanche breakdown, a phenomenon which occurs when the device voltage is exceeded. Unlike SCRs and gas gaps, the voltage does not drop to a small fraction of the "striking" voltage upon initiating current flow. Hence, there is no need for a series voltage dropping resistor in dc circuits. The solid state avalanche phenomenon is fast.

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