# ELECTROSTATIC DISCHARGE (ESD) GENERATED ELECTROMAGNETIC INTERFERENCE (EMI)

**Guidelines to improve the EMI immunity of equipment through design techniques are discussed.**

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## INTRODUCTION

Electrostatic discharge, commonly known as ESD, can cause serious damage or upset to electronic equipment. Semiconductor specialists and equipment users are taking a number of ESD prevention measures. Considerable effort is being spent to develop ESD simulators for simplifying and standardizing ESD testing. However, the ESD-radiated fields have received significantly less attention. These radiated electromagnetic fields can upset or damage adjacent equipment or circuitry by bypassing terminal protection devices. The EM energy propagates in two routes -- conductor surfaces and space -- in the form of the impulsive EMI energy over a frequency region. The influences of EMI energy propagating in space can be recognized from the fact that electronic equipment may operate erroneously even when there is no direct passage of the discharge current to it.

A recently published paper indicated that the energy deposited in an integrated circuit on a printed circuit board is shown to be proportional to the product of the peak value of the E-field and its derivative.[1] A similar derivative effect was stated in another paper.[2] There, the energy coupled to a short monopole over a small ground plane was found to be proportional to the "WARP" (Working Amplitude Rate of Change Product). The WARP was defined as the product of the peak voltage times the peak derivative of the discharge current times the monopole's effective area.

## ESD EVENT AND EMI GENERATION

When two objects are in contact, one tends to attract electrons away from the other, so that each develops a different charge voltage level. Objects accumulate charge either triboelectrically or inductively. Triboelectric charging is a mechanical process whereby relative surface motion transfers charge. Charge transfer depends on the amount of contact, surface smoothness, humidity, contact pressure, the triboelectric properties of the rubbing materials, and the rate of relative motion. The voltage to which a person or cart can be charged is highly dependent on their capacitance.

Induction charging is the result of exposing an ungrounded object to an electrostatic field. The voltage difference between two objects will induce a current, transferring enough of the charge to equalize the voltages. This rapid transfer of charge is known as ESD. During this process, it causes potentially devastating voltage currents and electromagnetic fields to occur.

The EMI energy associated with ESD may have an upper frequency limit exceeding 1 GHz, depending on the voltage level, relative humidity, speed of approach and shape of the charged object. At such frequencies, typical equipment cables and even traces on printed-circuit boards (PCBs) become fairly efficient receiving antennas. Thus, ESD tends to induce high levels of noise in typical electronic equipment, both analog and digital.[3]

Honda and Ogura have performed field measurements for various ESD events.[4] A pair of collinear conductive cylinders are charged and one is suspended above the other; eventually the upper cylinder is dropped to bring them together and create a spark. Their measurement indicates a fairly broadband spectrum which widens with increasing voltage up to about 10 kV, and then begins to decrease as the corona increasingly dissipates the energy before the main discharge. They noted that most of the ESD energy was at frequencies below 2 GHz. However, ESD spectral distribution will depend on the current waveform, conductor geometry, measurement position, etc., in addition to the charging voltage.

## CHARACTERISTICS OF EMI

Honda experimentally determined that the EMI action has no direct relation of proportionality to the charged potential of the object, as mentioned earlier.[5] Upon an ESD, the electromagnetic field appearing in the vicinity of the wave source has a general tendency to appear as a sharply rising impulse of small time width when the voltage is relatively low, but becomes a damped oscillation of large time duration as the voltage is increased.

Honda measured typical EMI characteristics with an ESD detector.[6] EMI was radiated from an ESD simulator whose discharge probe was hand-held. The discharge electrode at the probe tip end was brought into contact with an alligator clip at the tip end of the grounding head. The range of the EMI radiated by the resulting spark was measured. The result is shown in Figure 1. It was noted that at a discharge voltage up to about 6 kV, the EMI range extends proportionally to the discharge voltage, but when the discharge voltage exceeds about 10 kV, the EMI range tends conversely to decrease. The reason why EMI is not always proportional to the voltage is that the rise time of discharge current elongates with increasing spark gap. Also, the frequency spectrum observed at some distance from the spark gap concentrates into the low frequency regions with increasing spark gap (increasing discharge voltage).

The ESD field problem has been studied analytically based on a simple dipole model.[7] The spark is modeled as an electrically short, time-dependent, linear source (or dipole) situated above an infinite ground plane. Radiated fields were found to be dependent on two factors: the magnitude of the transient current and its rise time. One factor may be more dominant than the other, depending on whether the observation point is in the near-field or farfield region of the ESD spark.

Electric fields tend to excite high-impedance antennas and voltage sensitive circuitry. Unwanted coupling can therefore be reduced by keeping the impedance of any potential receiving antenna low. This may enhance magnetic field pickup since magnetic fields can penetrate low-impedance shields more effectively than electric fields. They also excite apertures and seams as do electric fields. They are best received by low-impedance antennas, especially circuit loops. Thus, avoiding loops might be a good design guideline but it is difficult to achieve because loops are often difficult to recognize.

Analytical analysis revealed that the near-field magnetic field, like the electric field, depends directly on the ESD current shape. Thus, the highest fields to be associated with the highest current levels would be expected. The far-field magnetic field is dependent on the time derivative of the current, as is the case with the electric field. Therefore, the low-voltage, fast rise time sparks cause the most interference to nearby equipment.

## EFFECT OF EMI IN ELECTRONIC EQUIPMENT

The fields due to ESD currents can penetrate equipment directly, or excite apertures, seams, vents, input-output cables, and the like, and couple to susceptible internal electronic circuitry. As the discharge currents flow within the system, they excite many antennas that exist in their path. The efficiency of radiation from these antennas is dependent primarily on the size of the antenna. The wavelengths of the frequencies resulting from an ESD pulse can range from centimeters to hundreds of meters. The electrical noise in the form of electromagnetic energy can cause damage or upset electronic equipment. Hanson and Prather studied the interaction of electromagnetic fields with electronic systems and subsystems. The interaction is conceptually shown in Figure 2.[8]

Electrical noise may enter electronic equipment by either conduction or radiation. In the near field of an ESD, within a few tens of centimeters, the primary type of radiated coupling may be either capacitive or inductive, depending on the impedances of the ESD source and the receiver. In the far field, electromagnetic field coupling exists.

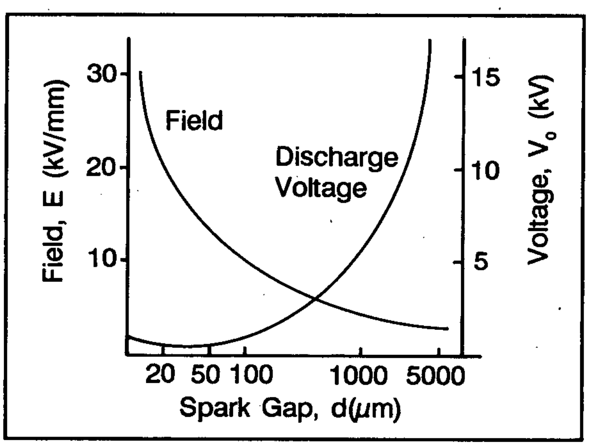


Figure 1A. Discharge Voltage vs. Spark Gap, With Field in the Spark Gap.

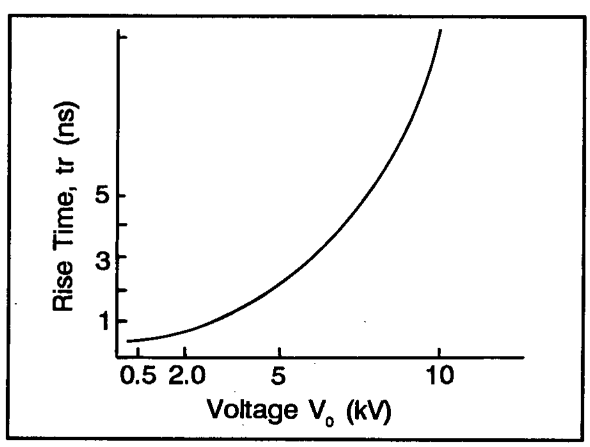


Figure 1B. Current Rise Time vs. Discharge Voltage.[6]

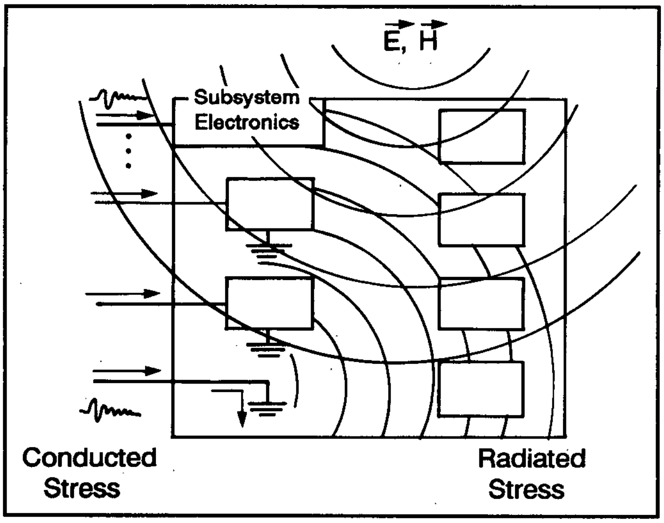


**Figure 2.** **Electromagnetic Interference with Electronic Systems and Subsystems.**[8]

Circuit operation is upset if the ESD induced voltages and/or currents exceed the signal levels in the electronic circuit. In *high impedance* circuits there is little current and the signals are voltage levels; *capacitive* coupling will dominate and ESD induced voltages will be the major problem. In the *low-impedance* circuits the signals are currents, so that *inductive* coupling will dominate and ESD-induced currents will cause the most problem.

The two primary damage mechanisms are: the thermal failure on devices due to heat created by ESD current, and dielectric breakdown due to ESD induced high voltage differentials. Both damage mechanisms may occur in a single device. For example, dielectric breakdown may trigger high current flow, which causes thermal failure.

Since the voltages and currents necessary to cause damage are one to two orders of magnitude greater than those necessary to cause upset, damage is more likely when there is a conductive coupling; that is, the ESD spark must directly contact the circuit lines. Radiated coupling will normally cause only upset.

## DESIGN GUIDELINES TO MINIMIZE THE EMI EFFECT

There are a number of ways to minimize the ESD generated EMI effect on electronic equipment: prevent ESD altogether, prevent the coupling of EMI into circuits or devices, and increase the inherent EMI immunity of equipment through design techniques.[3]

Preventing ESD altogether is possible for equipment used in an environment that controls ESD. But for equipment used in the field, design techniques should be applied to enhance the EMI immunity of the system. One common design technique is to incorporate protection circuits between critical points in the device such as input and ground. These circuits are enabled only when the ESD induced voltage exceeds a set limit. They provide alternate low-impedance paths along which the static charge may safely flow to ground. Protection circuits may include more than one current-shunting element -- one that would turn on quickly and carry the ESD current only until the second, more robust, element is activated. The protection elements within ICs are primarily responsible to prevent device destruction. In order to prevent equipment operational upset such as computer lock-up, the electronic circuits that incorporate the ICs must have additional protection measures.[3,9]

## ADDITIONAL PROTECTION MEASURES

*The circuit design* should have no wait or disable states with unlimited duration.

*Unused inputs* on devices must not be left unconnected or floating.

*Filters* (shunt capacitive or series inductive or a combination of the two) should be used in the circuits to prevent EMI from being coupled to devices. If the input has high impedance, a shunt capacitive filter (using capacitors with very low stray inductance) will be the most effective because its low impedance will effectively bypass the high input impedance. The shunt capacitor must be as close as possible (within 3-4 cm of the device pin that they are to protect) to the input. If the input impedance is low, a series ferrite (inductor) will provide the best filter. The series ferrite should be as close as possible to the input.

*Transient suppressors* that can switch into action in less than 1 nanosecond can be used instead of shunt capacitors. Such suppressors can have up to hundreds of picofarads of capacitance until they turn on and begin conducting.

*PCB design* plays an important role in developing system immunity to ESD. The tracers on a PCB are antennas for ESD generated EMI fields. To minimize the coupling to these antennas, line lengths must be kept as short as possible and loop areas must be kept as small as possible. Also, common-mode coupling is enhanced when components are not spread evenly over the entire area of large boards. The use of planes or grids to reduce coupling also tends to keep radiated noise common-mode because of the close coupling between signal lines and their return.

*Enclosure design* is another critical aspect of preventing both radiated and conductive coupling of EMI. A completely enclosed conductive metallic enclosure will tend to shield the circuits from radiated noise, but conductive coupling may occur due to secondary arcs from the shield to the circuits. Thus some enclosure designs utilize an insulating enclosure and within this, a metallic shield. Compromising the integrity of most enclosures are holes, outlets for air, screws, etc. The use of several small holes instead of a single large one is better from an EMI-prevention viewpoint. The sides of a seam should be electrically connected at frequent intervals to reduce EMI noise.

A properly designed *cable protection system* can be the key to achieving system EMI immunity. As the largest antennas within most systems, cables are particularly prone to having large voltages and/or currents induced in them by radiated EMI. On the other hand, cables can indirectly help prevent conductive coupling by providing a low-impedance path along which the charge may leave the system if the cable shield is connected to chassis ground. To minimize radiated EMI coupling in cables, line lengths and loop areas are minimized, common mode coupling is encouraged, and the circuit lines are surrounded with metallic shielding. A cable shield must be connected to enclosure shields at both ends of the cable.

In addition to hardware solutions, *firmware and software EMI solutions* are powerful methods for reducing the severity of upsets such as system lockup. Firmware and software ESD preventive measures fall into two general categories: refreshing, checking and restoring. Refreshing involves resetting rest states periodically, and refreshing the display and indicator status -- nothing should ever be done just once and then assumed to be correct. Checking subroutines should be used to determine whether the program is flowing properly. They can be activated at intervals to verify that the program has performed certain functions. If those functions have not been performed, then a recovery program will be activated. Details of firmware and software solution techniques are available in the literature.[9]

## SUMMARY

Electromagnetic energy generated by ESD could cause upset and even damage electronic equipment. The electrical noise (EMI) can affect electronic equipment either by conduction or by radiation. The energy coupled to an integrated circuit in the equipment is proportional to the product of the peak E-field and the derivative of the E-field. Guidelines to improve the EMI immunity of equipment through design techniques are discussed. ■

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