EMC Engineering: The Crossroads of Personnel Safety and Product Reliability

Knowledge of threats, coupling mechanisms, and hazards will enable management to better understand the EM environment and the EMC issues associated with high-technology products.

MOSHE Z. NETZER, RAFAEL
Haifa, Israel

INTRODUCTION

Electromagnetic compatibility (EMC) is a branch of electrical engineering that utilizes analytical methods, design practices, test methods, and solution components to enable an electronic system to function properly within its intended EM environment and to meet specific interference control limits. The electromagnetic environment contains threats which EMC engineering must address: electromagnetic radiation (EMR) and electrostatic discharge (ESD).

EMR, ESD and electrostatic fields have positive effects utilized for the benefit of mankind, but their unwanted effects must be considered. EMR and ESD couple onto electronic components, circuits and assemblies. Manmade radio frequency EMR is efficiently generated by antennas and propagates from them. Non-ionizing EMR can cause biological effects, and can be hazardous to personnel. ESD is a natural phenomenon that manifests itself via lightning strikes, electric fields, and discharges from human beings and from furniture. ESD can ignite hazardous materials. Both threats — EMR and ESD — affect the reliability of electronics and personnel safety.

The EMC engineering discipline is indeed the crossroads of personnel safety and product reliability. This article reviews EMR and ESD with respect to safety and reliability, which reflect the quality of an engineering process, the quality of a product, or an overall environmental quality. Basic parameters are detailed, including modes of generation and coupling mechanisms, frequency, rise time, and peak and average amplitudes, all of which play a role in defining the threats and their consequences concerning reliability and safety.

A FORMULA FOR QUALITY

A thorough understanding of threats, coupling mechanisms, and hazards will enable management and technical staff who are responsible for the safety of their personnel and quality of their products to have better insight into the EM environment and the EMC issues connected with high-technology products.

Dr. Dov Froman, general director of Intel Israel, proposed an interesting formula for achieving maximum quality: safety and responsibility. "The Israelis," he said, "tend to separate safety from quality: quality is not an issue in safety conferences, and vice versa, safety is not an issue in QC symposia. This disassociation between safety and quality is totally unjustifiable. Safety is a distinctive reflection of quality. Moreover, where quality is judged by performance, process upgrading, competition and teamwork, safety, on the other hand, is judged by human life preservation, the most precious resource on earth."

Dr. Froman's equation should include reliability, i.e., safety plus reliability plus responsibility equals quality. The association between quality and safety that Dr. Froman ingeniously pointed out gives rise to the safety-quality-reliability linkage associated with electromagnetic compatibility (EMC) issues. These include EMR coupling to electronics, electroexplosive devices and human tissues; ESD in electronics and in the presence of an explosive/flammable environment; and qualification testing of electroexplosive devices (EED) for safety and reliability.

EMC situations comprise three elements.

- EMI source that is quantified by noise, power, energy, voltage, current field, etc.
- Victim, the susceptibility of which is quantified by the threat's terms and units (power, field, etc.)
- Coupling mechanism or path mode whereby interference is coupled from the threat source to the victim.

EMC is said to be achieved when the following inequality is obtained:

$$N \times T < S/M$$

where
M = Safety margin
N = Threat
T = Coupling
S = Victim

These three EMC elements are depicted in Figure 1. Safety margins can vary. For example, 6 dB may be

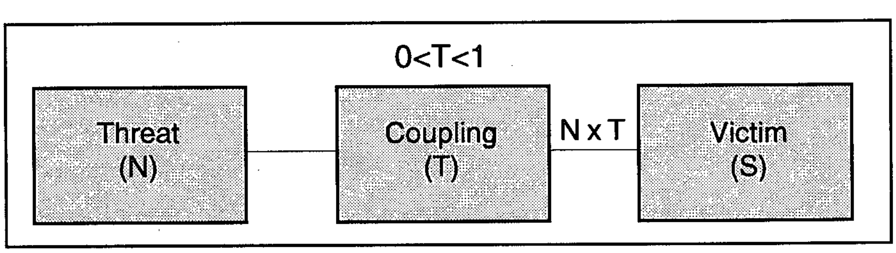


***Figure 1.** Elements of EMI.*

sufficient when reliability aspects are involved, but 20 dB is necessary when the lack of EMC might lead to catastrophes.

ELECTROMAGNETIC RADIATION (EMR)

EMR can be classified in terms of safety or reliability. Manmade radio frequency EMR becomes a safety issue when it is coupled onto electroexplosive initiation leads, causes hyperthermia in biological tissues, or adversely affects critical mission electronics such as a flight control system. EMR becomes a reliability issue when interference to electrical and electronic circuits causes degradation of performance or system malfunction.

EMR signals are often classified as narrowband or broadband. Since narrowband and broadband are relative terms, some signals can be classified in either category. Nevertheless, this "narrow" and "broad" division becomes useful for understanding and analyzing conducted and radiated EMI effects. In general, a narrowband signal occupies a very small portion of the radio spectrum. Such signals are continuous sine waves (CW). Communication transmitters such as single-channel AM, FM and SSB fall into this category. Spurious emissions, such as harmonic outputs of narrowband communication transmitters, prime power signals and their harmonics, local oscillators, and many other manmade sources are narrowband emissions.

A broadband signal may spread its energy across hundreds of megahertz or more. This type of signal is composed of narrow pulses having relatively short rise and fall times. Broadband signals are further divided into random and impulse sources. These types of pulses may be intentionally generated by a noise jammer or unintentionally produced by communication and radar transmitters, or arcing from electric switch contacts. They may also be a result of galactic and solar noise, lightning electromagnetic pulses (LEMP), and by radio frequency pulses associated with electrostatic discharges.

Table 1 lists narrowband and broadband manmade interference sources. The table has been subdivided to give a general indication of whether the source involved is in operation for long periods (continuous), for short periods (intermittent), or for very short and infrequent periods (transient). The level of those sources on this list that can cause safety and/or reliability problems is discussed in many textbooks, standards and specifications regarding EMC.[1-3]

The magnitude of narrowband radiated emissions is generally expressed in terms of volts per meter (V/m). Volts per meter per MHz (V/m /MHz) is the expression used for broadband emissions. The time during which an EMI signal is incident on a victim determines the coupled energy. When EMR safety is under con-

BROADBAND SIGNALS (EMI)			NARROWBAND SIGNALS (EMI)	
Transient	**Intermittent**	**Continuous**	**Intermittent**	**Continuous**
Mechanical Function Switches	Electronic Computers	Communication Noise	CW-Doppler Radar	Power-line Hum
Motor Starters	Motor Speed Controls	Electric Typewriters	Harmonics of Radio Transmitters	Receiver Local Oscillator
Thermostats	Poor or Loose Ground Connections	Ignition Systems	Signal Generators, Oscillators, and Other Types of Test Equipment	
Timer Units	Arc Welding Equipment	Arc and Vapor Lamps	Transponders	
Thyratron Trigger Circuits	Electric Drills	Pulse Generators	Diathermal Equipment	
		Pulse Radar Transmitters		
		Sliding Contacts		
		Teletype Writer Equipment		
		Voltage Regulators		

Table 1. *Manmade Interference Sources.*

sideration, terms such as continuous waves (CW), average power and average EMR level will be used. These are factors that imply large quantities of power or energy. Nonetheless, few safety failure scenarios associated with EMR coupling to electronics involve minute energies, as is evident when compatibility problems occur during an aircraft mission.

Coupling mechanisms between EMI sources and victims can take one or more paths, including radiation (antenna-to-antenna, antenna-to-cable, or antenna-to-box); capacitative and/or inductive coupling (cable-to-cable); or common impedance (common ground and/or power supply). Various EMC techniques and components are available whereby EMI coupling can be efficiently reduced to a minimum (the transmission factor approaches zero). These techniques include signal- and power-line EMI filtering (to reduce conducted interference); magnetic and electromagnetic shielding, zoning, and use of fiber optic transmission lines (to reduce radiated coupling); balancing, twisting and screening of cables (to reduce radiation and induction coupling); and single point grounding (to reduce low frequency common-mode EMI).

ELECTROSTATIC DISCHARGE (ESD)

Static electricity is the most ancient form of electricity known to man. Two thousand years ago the Greeks had already recognized the triboelectric effect: two different materials when rubbed together and subsequently separated generate static electricity. ESD may have different manifestations: human-borne ESD, precipitation static (P-static) in aircraft, and lightning storms. Lightning strikes are, in fact, an enormous static discharge from cloud to earth or from cloud to cloud. In 1753, Benjamin Franklin introduced the "lightning rod." The use of the lightning rod spread rapidly through North America and Europe and eventually became a common lightning protection method throughout the world, known as the "Franklin Rod." Thus, destructive power resulted in the first connection between ESD and safety.

Like EMR, ESD can be classified in terms of safety and reliability. ESD can provide the energy required for ignition or explosion of hazardous materials, explosives, pyrotechnics, flammable gases and vapors, and organic powders. Reliability is affected when ESD causes EMI or destroys sensitive electronic components, such as integrated circuits (IC, VLSIC, ULSIC), metallized traces, and thin and thick film resistors.

Human-borne ESD, and ESD from tools, furniture, and other electrostatically charged materials have been identified as the probable cause of several explosions and fire events in the industry. ESD has ignited fires and caused detonation of various materials and components, such as agricultural dust in the grain industry and flour mills; explosives, pyrotechnics and propellants in the military; and volatile and flammable fluids in the chemical and oil industry.[4] Depending on temperature and ignition energy or the flash point in liquids, powders (dust) and flammable liquids may form explosive air mixtures that can be ignited by any type of ignition source, including ESD.

EMI failure modes may involve minute amounts of energy, as evident when electromagnetic compatibility problems occur during the flight of an aircraft. Under various flight conditions, an aircraft will accumulate electrical charges generated by the friction of the fuselage with dust, rain, snow and ice crystals. This type of static accumulation, which is known as precipitation static (P-static), increases the aircraft static potential up to 100,000-300,000 V relative to ground. Discharges of P-static via corona, arcing and ion streams can generate severe radio frequency interference (RFI) that compromises the safety of flight due to RFI coupling with the aircraft communication and navigation antennas in the VLF, HF, VHF, and UHF frequency ranges. RFI generated from P-static discharges may block radio communication systems and adversely affect the flight control system and other avionic systems on an aircraft.

Semiconductor components in general and chips of integrated circuits in particular are extremely sensitive to ESD. The trends in semiconductor technology toward thinner dielectric layers, increased transistor density and decreased bias voltages inevitably imply increased chip sensitivity to ESD. Unfortunately, ESD-related failures are often ascribed to other causes, such as power transients, manufacturing defects, random failures, thermal effects, etc.

Moreover, there are many misconceptions pertaining to the ESD threat. These include the beliefs that only MOS parts are affected; an ESD-sensitive device that is mounted on a PC board or assembled in a unit grants ESD immunity; and that ESD generation is controllable. Erroneous perception of the ESD threat and inexperienced personnel who fail to track down the prime causes for production failures can delay the implementation of essential ESD control measures that should be taken in the production line and in the maintenance shop.

ESD coupling modes may take different forms: triboelectric charging, static field, direct discharge, or EM field generated by static arc-over (Figure 2).

A human being is a common carrier of static charges. The typical static charge on personnel wearing insulating shoes is 16,000 V. It is clear, therefore, that neglect of this threat, particularly in the high-technology industries, can lead to an intolerable reduction of production yields due to extensive damage to ESD-sensitive devices during the handling and manufacture of a product. The range of ESD vulnerability based on device technology (VMOS, MOSFET, GaAsFET, etc.) is presented in many textbooks and publications on EMI and ESD control.[1,5,6]

Static control measures must be implemented throughout all handling and production levels: processing, assembly, inspection, packaging, shipping, storage, stowage, testing,

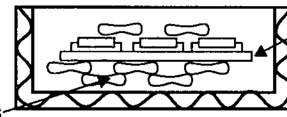
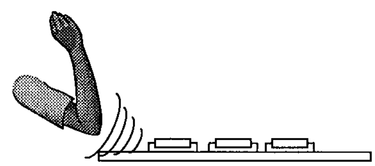
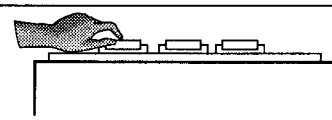
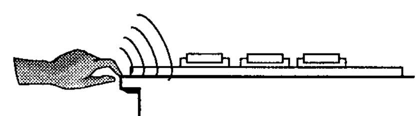
COUPLING MODE	COMMON CAUSE	EFFECT
Direct Charging	• Inadequate handling/shipping	• IC cases (plastic) charge and arc internal to part 
Static Field	• Ungrounded personnel • Nearly charged clothing • Inadequate shipping precautions	• Differential charging on PCBs causes currents; also, secondary arcing may occur 
Direct Discharge	• Ungrounded personnel • Charged materials	• Arcing (20 kV) causes high-pulse currents, probable damage 
EM Field	• Arcing near equipment	• Field coupling into loops on the board and wiring, causing high E&H fields, logic upset and possible damage 

Figure 2. *Coupling Mode, Causes and Effects.*

installation and maintenance. To ensure proper implementation of ESD control methods, an ESD control program should be followed.[5,7] The program's prime topics are training and education; establishing ESD-protected areas (EPA); establishing handling procedures for ESD-sensitive devices; and performing periodical checkups and audits to verify correct implementation of the ESD control program. In terms of increased production yield and preservation of a company's reputation as a manufacturer of reliable products, the cost of a comprehensive ESD control program pays off almost immediately.

CONCLUSION

Electromagnetic compatibility (EMC) is an interdisciplinary engineering field that provides methods and tools to ensure system compatibility within an intended EM environment. The electromagnetic environment contains threats which might impair product reliability and personnel safety. This article surveyed several EMC topics associated with two major EMI threats: electromagnetic radiation (EMR) and electrostatic discharge (ESD). EMR and ESD coupling onto electronic components, circuits and assemblies can cause reliability and safety degradation. ESD can cause the ignition of hazardous materials. EMR can cause biological effects and can be hazardous to personnel. Using proven EMI control methods, EMR and ESD can be harnessed for the benefit of mankind, while coupling of EMI to potential victims can be minimized to levels below those which affect reliability and/or safety.

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***MOSHE NETZER** received a BSEE degree from the Technion, Israel Institute of Technology, Haifa, in 1976. He joined RAFAEL Company, Electromagnetics Division, Haifa, Israel, in 1976 as an EMC engineer, and since 1982 has been a group leader working in the field of EMI in communications, RADHAZ, ESD control, and classic EMC/EMP design and analysis. In 1985-86 and in 1990 Mr. Netzer enjoyed sabbatical positions as a Senior Engineer at R&B Enterprises, West Conshohocken, PA. He is a senior IEEE member and a NARTE-certified EMC engineer. FAX: 972-4-8347186.*