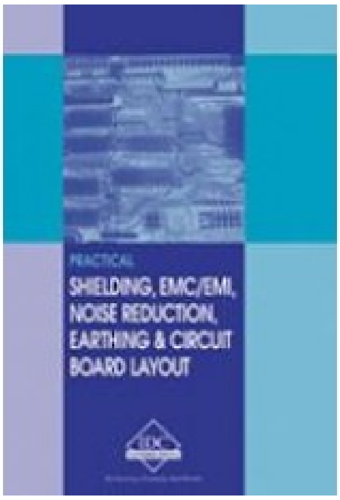
SG-E - Practical Shielding, EMCEMI, Noise Reduction, Earthing and Circuit Board Layout



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Short Description

The aim of this manual is to help you identify, design, prevent and fix common EMI/EMC problems with a focus on earthing and shielding techniques. Learning how to fix earthing and shielding problems on the job can be very expensive and frustrating. Although it must be noted that most of the principles involved are simple, this manual will give you the tools to approach earthing and shielding issues in a logical and systematic way. This manual focuses on the issues of interest to you if you are working in design, operation or maintenance of analog or digital systems involving sensors, data acquisition, process control, cables, signal processing, programmable logic controllers, power distribution, high speed logic etc.

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signal processing, programmable logic controllers, power distribution, high speed logic etc.

The circuit board layout section concentrates on design and layout of circuits and components on a printed circuit board. The overall focus is on useful design and systems issues; not about regulations and standards. The idea is that you will take this material with you and apply the key principles immediately to your design and troubleshooting challenges.

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1. **Introduction Electromagnetic Compatibility**

1 Introduction

1. Introduction

Electromagnetic Compatibility (EMC) is defined as *the ability of a device, equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbance to anything in that environment*. Any electronic equipment is both capable of emitting unintended signals (i.e., interference to other electronic equipment) and also itself being affected by spurious radiation from other electronic equipment (i.e., interference caused by other electronic equipment). Putting these electronics together without affecting each other is the challenge. Meeting the challenge is a combination of legislation, engineering and consideration for the needs of others.

1.1.1 EMC – accepting the challenge!!!

Historically, EMC has been concerned principally with ensuring the proper operation of collections of electrical and electronic apparatus. Since interference is a function of separation distance, equipment used in close proximity to other equipment had to be *compatible* with its neighbors. Putting together a *system* out of several essentially different items of *apparatus*meant that these items were naturally close to each other, and their Electromagnetic Compatibility (EMC) was necessary in order for the system to work successfully. Hence the discipline of EMC grew up in those industry sectors where system integration was the norm. In the military, the majority of electrical and electronics equipment is used on *platforms* i.e., ships, aircraft and land vehicles, in their civilian equivalents, aerospace, rail, automotive and marine transport, and in the process control industry. The consumer, IT and professional equipment sectors largely escaped this discipline, because their individual products could assume a large enough separation distance that EMC could be regarded as a luxury rather than a necessity.

Commercial systems that faced issues of safety integrity had often to meet requirements for immunity from various phenomena such as radio frequency (RF) fields, electrostatic discharge (ESD), and various types of conducted transients. But these were contractual requirements, agreed between the equipment suppliers, and the system designers and operators. They were instigated as a result of operational experience, not because of legislation.

There is now an urgent need for mandatory measures to be taken to protect and ensure equipment EMC. Various national administrators have taken ad hoc measures in the past to impose restrictions on some of the electromagnetic properties of some types of products. These measures have often come to be seen as implementing back-door methods of protection, without the technical adequacy of some of the requirements allowing effectively different standards to be applied to imported and indigenous products. In an effort to recognize the need for EMC protection measures and at the same time to eliminate the protectionist barrier to trade throughout the European Community, the European Commission adopted in 1989 a Directive *on the approximation of the laws of the Member States relative to electromagnetic compatibility,* otherwise known as the EMC Directive.

At times, EMC problems and their solutions do seem like *black magic* rather than engineering. Here are few of the examples…

- This is an instance from the **Falklands war**: HMS Sheffield turned off its missile warning RADAR because it interfered with the satellite communication system of the ship. The result of this was – HMS Sheffield was sunk by an enemy missile, which could otherwise have been detected.
- An engineering company installed a CAD system to speed up design time. However, the system crashed so often that they were falling even further behind. Numerous calls to the suppliers failed to solve the problem that everyone thought was software-related. Investigation showed

eventually that a large drawing reproduction machine that injected transients onto the mains supply caused it.

- In **February ’99**, while approaching JFK airport, a DC 10 passenger airplane banked hard left all by itself, almost crashing. The cause of it was suspected to be a CD player being played in 1st
- Much of the bad press surrounding CD players and aircraft seems to have originated with a Lufthansa flight where a system operating at 112 MHz had problems which were traced to a CD player with a clock rate of 28 MHz. The system operating frequency is equal to 4 times the clock rate of the CD player.
- A paper mill in Stanger (South Africa) was experiencing trips on its 1 MVA variable speed drive system. A voltage dip of 20%, lasting for more than 40 ms was enough to trip the system and would result in several hours of downtime while the paper web was re-threaded and the system started up again. Installation of a SMES (Superconducting Magnetic Energy Storage System) has meant that there have been no further system trips since 1997.

In an aerospace factory, a plastic welder was being operated quite legally. Nearby is a mattress factory. Although both are tens of meters away from each other, the welder caused a mattress to burst into flames.

Here is a statement (which may sound familiar) given by the past chairman of the Scottish branch of the Institute of Structural Engineers ‘ … the art of modelling materials we do not understand, into shapes we cannot precisely analyse, to withstand forces we cannot properly assess, in such a way that the public at large has no reason to suspect the extent of our ignorance’.

In this workshop, we will be looking at engineering ways to prevent and solve EMC problems without the need for witches, wizards and other supernatural means.

1. EMI vs EMC

Electromagnetic interference (EMI) is a serious and increasing form of environmental pollution. Its effects range from extremely small annoyances due to crackles on broadcast reception, to potentially fatal accidents due to corruption of safety-critical control systems. Various forms of EMI may cause electrical and electronic malfunctions, can prevent the proper use of the radio frequency spectrum, can ignite flammable or other hazardous atmospheres, and may even have a direct effect on human tissue. As electronic systems penetrate more deeply into all aspects of society, so both the potential for interference effects and the potential for serious EMI-induced incidents will increase.

The threat of EMI is controlled by adopting the practices of electromagnetic compatibility (EMC). The term EMC has two complementary aspects:

- It describes the ability of electrical and electronic systems to operate without interfering with other systems
- It also describes the ability of such systems to operate as intended within a specified electromagnetic environment

Thus it is closely related to the environment within which the system operates. Effective EMC requires that the system is designed, manufactured and tested with regard to its predicted operational electromagnetic environmental (i.e., the totality of electromagnetic phenomena existing at its location). Although the term *electromagnetic* tends to suggest an emphasis on high frequency field-related phenomena, in practice the definition of EMC encompasses all frequencies and coupling paths, from DC through mains supply frequencies and microwaves.

1. Interference sources

Figure 1.1

Devices that cause continuous noise

There are two types of internal and external interference, viz., continuous and intermittent. Each type has its own cause.

The most common causes of continuous interference are:

- 50/60 Hz Supply Power
- Electric Motor (Especially Commutator Type)

- High Power Radio Signals
- Switch Mode Power Supplies
- Microwave Ovens
- Ignition Circuits

Devices that cause constant noise emissions are usually easier to find than intermittent noise problems. This is because the noise doesn't go away while the system is being looked at. The most common constant noise source is hum, caused by a 50/60 Hz supply power. Supply power is the most common noise component because it is an oscillating voltage, has high power and has a huge antenna system. Almost every system has some form of power filtering for 50/60 Hz supply power. This filtering can take the form of either trying to keep 50/60 Hz noise from getting into our device or leaving the device.

High power electric motors often create wideband noise. They can radiate noise into almost any equipment that is in close proximity to the motor. DC motors often have switch mode power supplies that cause high frequency noise through the common power ground. As motors ramp up and down the noise can vary in frequency and power. This wideband motor noise can then be transmitted back through the power supply lines or through a common earth ground.

Local radio, television stations, radar and ham radio stations can cause radio frequency noise. Military radar is the highest power radio system, but TV, AM and FM local radio stations are usually more common. These stations put out kilowatts of power and often are relatively close to industrial areas.

Switch mode power supplies are fast becoming the most common noise source of all. This is because they are so popular as a low voltage plug pack in home electronics. They create large amounts of harmonic frequencies. The power supplies develop low voltages from mains power by switching the high voltage on and off very quickly that creates lots of noise. The wires that connect the power supply to the device then transmit this noise. Switch mode power supplies are very popular because they are not frequency or voltage dependent and can be used in any country and on almost any device.

Microwave ovens radiate wideband noise by leakage through edges of the door or from the power supply wires. The oven can transmit hundreds of watts over short distances. While this is good for cooking the food, it also can create life-threatening situations for people with pacemakers. Ignition circuits in motorcycles, cars and other gasoline powered motors put out wideband noise created by tens of thousands of Volts. Most automobiles have some sort of suppression circuit, but if this fails it can cause havoc with it's own electronics and nearby devices. Older motorcycles, lawn mowers and other simple engines often have little or no noise suppression and therefore emit large amounts of noise.

Devices that cause intermittent wideband noise are:

- Lightning
- Switching Relay Equipment
- Arc Welding
- Static

Figure 1.2

Devices that cause intermittent noise

Intermittent noise components are often hard to find. There is an old saying in electronics... *If it's not broke, it can't be fixed*. And since the noise comes and goes the problem is usually only present part of the time.

Lightning can be the most damaging of the intermittent noise. A typical lightning strike can contain 20 to 40 thousand Amps and millions of Volts. In addition, the lightning strike transmits wideband noise that covers the whole frequency spectrum from DC to X-rays. This, in conjunction with the high current and voltage, makes it impossible to filter out lightning noise. The best method is to keep the lightning away from the circuit by using protection devices like shunts and suppressors.

Turning off relays usually causes relay switching noise. This noise is created by the magnetic field collapsing when the relay is turned off. This type of noise is common in industrial environments.

Arc welding is man-made lightning and has all the attributes of lightning such as high current, high voltage and wideband frequency noise. The advantage here is that it is often very intermittent and can be easily recognized.

Static is very hard to prove as a noise source as it is often invisible and very intermittent. Although is often man-made, it can be natural in origin. Equipment can be *spiked* by static build up in the air as well as from a person. Static noise is also very similar to lightning with all the same attributes except on a smaller scale.

1. Need for standards

Standards are required to control interference from the electronic devices, i.e., to make electronic devices less susceptible to interference. Various countries implemented their own standards, some of the standards are as mentioned below:

- **IEC**(International Electrotechnical Commission) – the IEC operates in close co-operation with the International Organization (ISO). It is composed of National Committees that are expected to be fully representative of all electrotechnical interests in their respective countries. Two IEC technical committees are devoted full time to EMC work is TC77, *Electromagnetic compatibility between equipment including networks*, and the *International Special Committee on Radio Interference* or CISPR.
- **CENELEC** (European Committee for Electrotechnical Standardization) and**ETSI** (European Telecommunications Standards Institute) – CENELEC is the European standards making body, which has been mandated by the Commission of the EC (European Commission) to produce EMC standards for the use with European EMC Directive. For Telecommunications equipment ETSI is the mandated standards body. ETSI generates standards for telecom network equipment that is not available to the subscriber, and for the radio communications equipment and broadcast transmitters.

Any manufacturer wanting to market his/her goods into a particular country has to comply with the standards followed by that country.

1. EMC – the issues

Figure 1.3

EMC issues

Figure 1.3 shows the EMC issues in a diagrammatic way. Any electronic device will emit radiation in the form of -

- Radiated RF electromagnetic disturbances from the device itself
- Radiated RF electromagnetic disturbances from its input and output connections

- Conducted EMD via its I/O connections or power lines

Any electronic device will be susceptible to EMD from –

- Stray radiation from other electronic equipment
- Stray radiation from the I/O of other electronic equipment
- Conducted disturbances via mains lines or I/O, or
- Mains voltage variations or waveshape

1.6 Electromagnetic disturbances

Any electromagnetic phenomenon may degrade the performance of the system. Some of the electromagnetic issues are as mentioned below:

- **Supply voltage**– Mains electricity suffers a variety of disturbing effects during its distribution. These may be caused by sources in the supply network or by other users, or by other loads within the same installation. A pure, uninterrupted supply would not be cost effective; the balance between the cost of the supply and its quality is determined by national regulatory requirements, tempered by the experience of the supply utilities. Typical disturbances are:

Interruptions

Dips

Surges

Waveform distortion

Fluctuations

Voltage imbalance

Frequency variations

DC in AC networks

Power-line carrier signaling

Voltage fluctuations: short-term (sub-second) fluctuations with quite small amplitudes are annoyingly perceptible on electric lightning, though electronic power supply circuits comfortably ignore them. Generation of flicker by high power load switching is subject to regulatory control.

Waveform distortion: at source, the AC mains is generated as a pure sine wave but the reactive impedance of the distribution network together with the harmonic currents drawn by non-linear loads causes voltage distortion. Power converters and electronic power supplies are important contributors to non-linear loading. Harmonic distortion may actually be worse at points remote from the non-linear load because of resonance in the network components. Not only must non-linear harmonic currents be limited but also equipment should be capable of operating with up to 10% total harmonic distortion in the supply waveform.

Voltage variations: the distribution network has finite source impedance and varying loads will affect the terminal voltage. Not including voltage drops within the customer's premises, an allowance of ±10%, on the nominal voltage will cover normal variations in the UK. The effect of the shift in nominal voltage from 240 V to 230 V, as required by CENELEC Harmonization Document HD 472 S1: 1988 and implemented in the UK by BS 7697: 1993, is that from 1stJanuary 1995 the UK nominal voltage is 230 V with a tolerance of +10%, –6%. After 1stJanuary 2003 the nominal voltage will be 230 V with a tolerance of ±10%, in the line with all other Member States.

Transients and surges: switching operations generate transients of a few hundred volts as a result of current interruption in an inductive circuit. These transients normally occur in bursts and have risetimes of no more than a few nsec, although the finite bandwidth of the distribution network will quickly attenuate all but local sources. High amplitude spikes in excess of 2 kV may be observed due to fault conditions. Even higher voltage surges due to lightning strikes occur – mostly on exposed overhead line distribution systems in rural areas.

Voltage interruptions: faults on power distribution systems cause almost 100% voltage drops but are cleared quickly and automatically by protection devices, and throughout the rest of the system the voltage immediately recovers. Most consumers therefore see a short voltage dip. The frequency of occurrence of such dips depends on location and seasonal factors.

- **Transient overvoltages** – transient overvoltages on supply, signal and control lines that may occur because of lightning, switching or ESD (electrostatic discharge) can degrade the system performance. Take an example of an EMC phenomenon caused because of an ESD transient. An ESD transient can corrupt the operation of a microprocessor or clocked circuit just as a transient coupled into the supply or a signal port.

- **Radio frequency fields** – radio frequency fields, pulsed (radar), modulated and continuous, coupled directly into the equipment or onto its connected cables, may also degrade the system performance to a great extent.
- **NEMP (nuclear electromagnetic pulse)**– this is the effect of a high altitude nuclear explosion, which generates a sub-nanosecond nuclear electromagnetic pulse (NEMP) that is disruptive over an area of hundreds of square kilometers.
- **LF magnetic or electric fields**
    1. EMC testing categories

Figure 1.4 shows the diagrammatic view of the EMC testing categories. The four categories are as follows:

- Conducted Emission (CE)
- Conducted Susceptibility (CS)
- Radiated Emission (RE)
- Radiated Susceptibility (RS)

Figure 1.4

EMC testing categories

All electronic devices are susceptible to electromagnetic disturbances, if it is not the case, then there would be no EMC issue. However, none of the electronic devices are completely immune and so the EMC problem still exists. *Electromagnetic Susceptibility* can be defined as the inability of a device, equipment or a system to perform without degradation in the presence of an electromagnetic disturbance. On the other hand, *immunity to electromagnetic disturbances*can be defined as the ability of a device, equipment or a system to perform without degradation in the presence of an electromagnetic disturbance.

1. The compatibility gap

The increasing susceptibility of electronic equipment to electromagnetic influence is being paralleled by an increasing pollution of the electromagnetic environment. Susceptibility is a function of the adoption of VLSI technology in the form of microprocessors, both to achieve new tasks and for those that were previously tackled by electromechanical or analog means, and the accompanying reduction in the energy required of potentially disturbing factors. It is also a function of the increased penetration of radio communications, and the greater opportunities for interference to radio reception that result from the co-location of unintentional emitters and radio receivers.

At the same time more radio communications means more transmitters and an increase in the average RF field strengths to which equipment is exposed. Also, the proliferation of digital electronics means an increase in low-level emissions that affect radio reception – a phenomenon that has been aptly described as a form of electromagnetic *smog*. Only legislation to limit the effects of interaction can solve the problem.

Figure 1.5

Compatibility gap

These concepts can be graphically presented in the form of a narrowing electromagnetic compatibility gap, as shown in Figure 1.5. This *gap* is of course conceptual rather than absolute, and the phenomena defined as emissions and those defined as immunity do not mutually interact except in rare cases. But the maintenance of some artificially-defined gap between equipment immunity and radio transmissions on the other hand, and equipment emissions and radio reception on the other, is the purpose of the application of EMC standards, and is one result of the enforcement of the EMC directive.

1. Emission, immunity and compatibility

Relation between emission, immunity and compatibility is as shown by graphical representation in Figure 1.6. As shown in the Figure, there are 3 different levels:

- The lowermost level is the *Emission level*; the maximum level in emission level is the *emission limit*. The emissions from the devices should be within this level and it should not exceed the *emission limit*.
- The uppermost level is the *Immunity level*; the minimum level in the immunity level is the *immunity limit*. The immunity of the devices should be within this level and it should not be less than the *immunity limit*.
- The middle level is the *Compatibility level*; the difference between the *Immunity limit*and the *Emission limit* is the *Compatibility Margin*. *Greater the compatibility margin, lesser the chances of EMC problems*.

For proper functioning of a system, the devices should be *compatible* (with respect to EM environment) and hence the term Compatibility.

Figure 1.6

Emission, Immunity and Compatibility

1. Causes and consequences of EMI

The consequences of EMI can be classified in different categories depending on its criticality. Some of the causes of EMI that results into these consequences are mentioned below:

- Malfunction of a safety-critical item of machinery
- Erratic operation of moving equipment
- A safety device to ignore a signal
- An operation to stop for no apparent reason
- Not carry out its intended function, but not cause any havoc as a result

The malfunction will fall into the below mentioned classifications depending on the type of damage or loss occurred.

- Catastrophic – death, major injuries, downstream consequences
- Critical – minor injuries, extensive damage
- Major – minor permanent damage
- Minor – temporary performance loss
- Inconsequential – loss of performance within tolerance, no human intervention needed

1.10.1 Test result classification

For an item of equipment to pass a test, the test result must be determined beforehand. An important part of achieving compliance with any regulation is that the specification details what will happen under EMI conditions. The test result can be classified as follows:

- Normal performance within specified limits
- Self-recoverable temporary degradation or loss of function

- Temporary degradation or loss of function that requires human intervention or system reset
- Degradation or loss of function due to physical damage; software or data corruption

1. Levels of compliance and EMC engineering application

1.11.1 Levels of compliance

There are different levels of EMC engineering. Figure 1.7 shows the *compliance structure*showing different levels at which designers and companies operate.

Figure 1.7

Levels of compliance

The four levels of compliance are as follows:

- Self-compatibility
- Minimum engineering/in-house standard
- Contractual compliance
- Special requirements

The above is useful to appreciate the change in engineering strategy – say a company was just struggling to make things works, but must now it must comply with specifications.

1.11.2 Levels of EMC engineering application

This course aims to equip with tools to design for and reduce EMI. Three main areas of application will be dealt with:

- PCBs
- Circuits/filters
- Screening

Figure 1.8

Levels of EMC Application Engineering

Proper grounding is underlying to all of the above areas and is also dealt with. *Figure 1.8* shows the different areas.

PCBs can be seen as the inner or primary line of defence. The circuits on PCBs are where EMI problems eventually start and end. Proper PCB layout is the most subtle and cost effective way of influencing EMI. It controls EMI coupling right at the source or receptor – the circuit.

Filters and special circuits are used around the inner PCB as a secondary control measure or line of defence. When a PCB layout only does not eliminate unwanted interference, extra circuits and filters are added. Extra circuits imply more real estate and costs. Protection devices and circuits fall into this category.

Shielding is the tertiary or outer line of defence. This includes cables, screens and enclosures. If both of the above areas of application do not suffice, shielding is needed. The least cost effective solution and sometimes a last brute force attempt at compliance.

The fourth area of application (although not a level) is *grounding*. It determines the effectiveness and way all three levels interact. Grounding is applicable to all three of the above areas. Grounding on PCB level between different types of circuits is crucial. Filters/protection do not work properly if poorly grounded. Grounding of cable screens and enclosures has a primary influence on its shielding effectiveness.