Meeting the Challenge:
The European Union's EMC Directive
"*Designing for EMC Compliance*"

By
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ABSTRACT

The EMC Directive 89/336/EEC, adopted in 1989, amended in 1992 and mandated from January 1, 1996, is one of the most complex of the ***European Union (EU)*** *New Approach Directives. It affects all sectors of industry, which supply electrical or electronic apparatus to the EU. This Directive applies to apparatus liable to cause Electromagnetic Disturbance or the performance of which is liable to be affected by such disturbance.*

The purpose of this paper is to render a little more understanding to the phenomenon of EMC and to provide some practical guidelines and techniques to bring equipment (appliances) into compliance with the EMC Directive. This paper covers two major segments. Part I describes the fundamentals, terminology and basic concepts of EMC and Part II briefly discusses some techniques and guidelines to design for EMC compliance.

INTRODUCTION

The EMC Directive 89/336/EEC, adopted in 1989, amended in 1992 and mandated from January 1, 1996, is one of the most complex of the European Union (EU) New Approach Directives. It is also the most difficult Directive to comply with and it affects all sectors of industry, which supply electrical or electronic apparatus to the EU. This Directive applies to apparatus liable to cause Electromagnetic Disturbance or the performance of which is liable to be affected by such a disturbance.

Most manufacturers are familiar with safety standards and understand the need to comply with these mainly due to the litigious society in which we live. Should you wish to sell your product in the EU, that product has to conform to the essential requirements of the EMC Directive. What does this really mean? If a product conforms to the Directive it means that it is in agreement with the standards. The only way that a product can be in conformity with the EMC Directive is to demonstrate compliance, either by testing or a Technical Construction File. in our Litigious society, product liability is such an issue, manufacturers understand the need to comply with Safety Standards. And the Safety standards essentially specify a way to do things so that the end product complies. Therefore Standards specify a way to do things, in other words if you maintain creapage and clearance distances to the standards the product will meet that part of the standard.

So following Safety Standards allow you to design a product that will comply as Safety Standards are really a set of rules or a set of guidelines. If you follow the rules throughout the design stage you will have a product that complies.

Not so with the EMC Standards. It is extremely (if not impossible) to design to comply with an EMC Standard. You can only demonstrate compliance to an EMC Standard by testing to that standard. EMC Standards therefore are not guidelines to compliance but guidelines and rules for EMC Testing.

You can apply good EMC Design practices but will still have to test the product to ensure compliance with the standard. So what I am going to share with you now is a set of good EMC practices to make complying with the EMC Standards less painful. It is still not painless but somewhat anaesthetized.

Safety standards are applied to either ensure fitness of use of the product (like will it operate under expected environmental conditions like temperature, humidity etc) or protect us from hazards like electric shock, fire, etc. So EMC should be regarded as perhaps another safety standard. A products immunity compliance ensures that a product will operate reliably when subjected to environmental EMI and the emissions from a product ensures a safer environment.

EMC FUNDAMENTALS

The Evolution of EMC

During a job interview, a young candidate when asked what he understood by EMI replied: "Whenever something goes wrong with a piece of electronic equipment and you cannot explain why – that's EMI!" A good explanation, but perhaps a little more depth is needed.

Radio Frequency Interference (RFI) was the precursor to Electromagnetic Interference (EMI). Regulations concerning RFI have existed since the early 50's. These regulations were primarily concerned with interference to radio and TV, hence the name Radio Frequency Interference. Due to increasing problems of RFI in a wide range of environments, more specific requirements were produced. The **International Electrotechnical Committee (IEC)** through **CISPR (International Special Committee on Radio Frequency Interference)** developed recommendations to test and measure interference. As RFI and its propagation became better understood and with the expansion of the usable frequency spectrum**, EMI (Electromagnetic Interference)** became the new buzzword.

Military disciplines were concerned, not only with EMI emissions emanating from their equipment, but also with the susceptibility of their sensitive electronic equipment to EMI in the environment. **Electromagnetic Compatibility (EMC)** encompasses both the emissions and the immunity (or susceptibility) portion of EMI. The proliferation of sensitive electronic equipment within the commercial environment made EMC the new concern.

Electromagnetic Compatibility

EMI can be described as the degradation of a device or system caused by an electromagnetic disturbance. An electromagnetic disturbance is any electromagnetic phenomena which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter. An example of EMI affecting living matter is the current controversy regarding portable cellular telephones causing brain tumors.

Therefore, an electromagnetic disturbance can be an unwanted signal or even a change in the propagation medium itself. A change in the propagation medium can attenuate the signal and have a direct effect on the level of disturbance.

EMC, on the other hand, can be described as the ability of different pieces of electrically operated equipment to work in close proximity to each other without causing any mutual interference. EMC therefore implies the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to any other equipment in that environment. EMC is a twofold occurrence and consists of emissions and immunity.

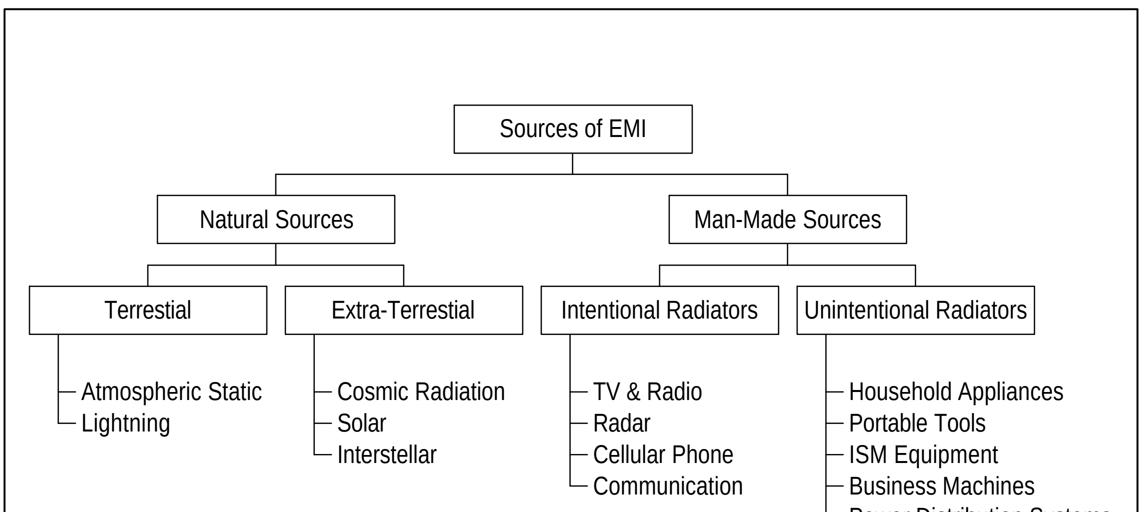
First, EMC implies that the equipment will not generate unacceptable interference emission levels which could cause interference (the emissions portion); and second, EMC implies that the equipment's intrinsic immunity levels are such that it can tolerate ambient levels of interference without degradation of performance (the Immunity portion).

Therefore, EMC means that a device must be capable of operating in all modes in the environment for which it was designed without degrading its own performance or that of any nearby equipment.

Sources of Electromagnetic Interference

An Electromagnetic Environment can be described as the electromagnetic conditions existing at a given location. The EMI environment includes interference emanating from natural sources like lightning and atmospheric static to the various man-made sources of interference such as vacuum cleaners, washing machines, power tools, computers, cellular phones, mobile radios and even electronic toys.

Natural sources can be either *terrestrial* or *extraterrestrial* in nature. Man-made sources include *intentional* or *unintentional* radiators (see figure 1 below). Within the scope of man-made noise sources we can break it down even further into *Inter-system* interference and *Intra-system* interference. Inter-system interference is EMI in a system caused by an electromagnetic disturbance generated by another system; whereas Intra-system interference is self-generated EMI present in a system.



Electromagnetic Interference Sources

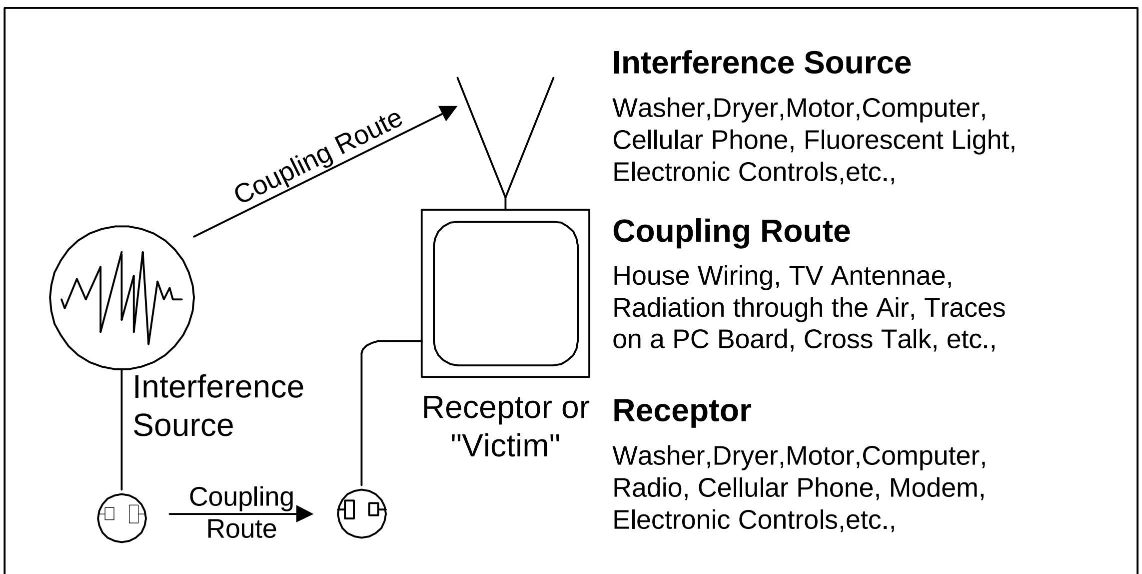
Figure 1

There is very little that can be done to prevent electromagnetic energy generated from natural interference sources. However, natural sources do not create that much of a problem except for perhaps, surges and spikes on power lines induced by lightning strikes. It is also very difficult to prevent EMI from intentional sources of electromagnetic energy. Cellular telephones and two-way radios are a major problem and can create havoc for example in hospital environments. It is therefore crucial that electronic equipment be made immune or less susceptible to environmental interference.

However, the major source of all interference is generated from ***unintentional man-made*** sources. This is due to the vast amount of electrical and electronic equipment in use.

The Three Elements of an EMI Problem

There are three essential elements to any EMC problem. There must be an EMI source or an electromagnetic disturbance, a receptor or "victim" that cannot function properly due to the electromagnetic phenomenon, and a path between them that allows the source to interfere with the receptor. This is shown in figure 2 below. Each of these three elements must be present (although they may not readily be identified) at the same time in order to have an electromagnetic disturbance or EMI. EMC problems can be solved by identifying at least two of these elements and eliminating or attenuating the interference from one of them.



The Three Sources of an EMI Problem
Figure 2

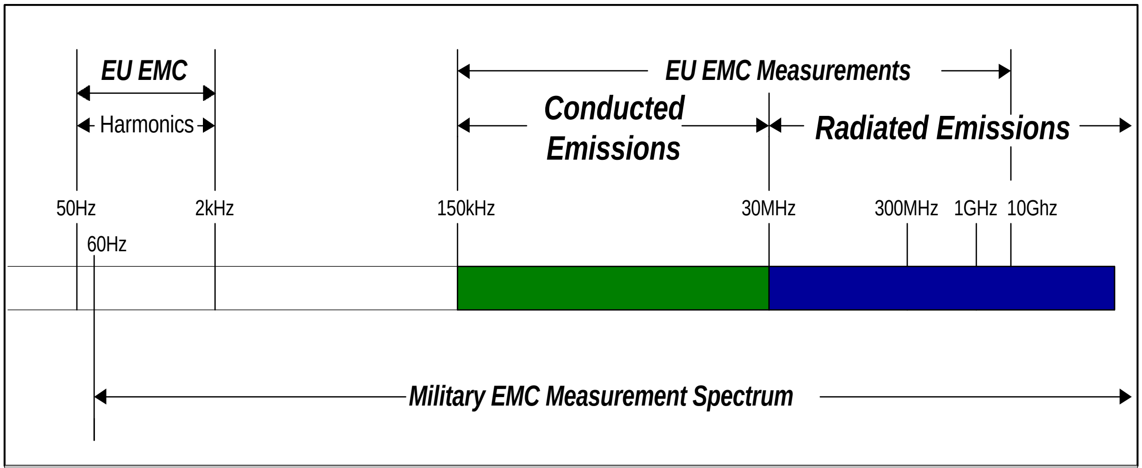
Characteristics of an EMI Source

Interference signals are established whenever electrons move. Therefore, any current flow may cause either direct coupling to other circuits or radiated fields, which may in turn couple unwanted signals into other circuits.

Sources of interference can be characterized by their *frequency, bandwidth and amplitude.* The frequency spectrum line chart shown in figure 3 depicts the frequency range with respect to EMC. The frequency range of concern for EMI from electrical apparatus is the harmonic range from 50 Hz (fundamental of the mains frequency) to 2 kHz (the 40th harmonic of the mains frequency), the conducted range from 150 kHz to 30 MHz and the radiated emission range from 30 MHz to 300 MHz and higher. Although we now only measure conducted emissions for the EU from 150 kHz, there is discussion of increasing the spectrum and starting from as low as 9 kHz. This could make it more difficult for manufacturers of SMPS, Inverters and SCR circuits to comply with the regulations.

The propagation medium of EMI below 30 MHz tends to be mains-borne or conducted. The interference travels along the power cord or signal lines from the source to the receptor or victim circuit. The conducted interference is not easily attenuated over distance.

The radiated portion of EMI emissions is borne as an electromagnetic wave, propagating through the air or any other non-conducting media. Generally, the higher the EMI in the frequency spectrum, the more easily it will radiate. EMI and EMC are becoming more of a problem due to the trend to produce equipment in smaller packages operating at very high speeds and processing rates.



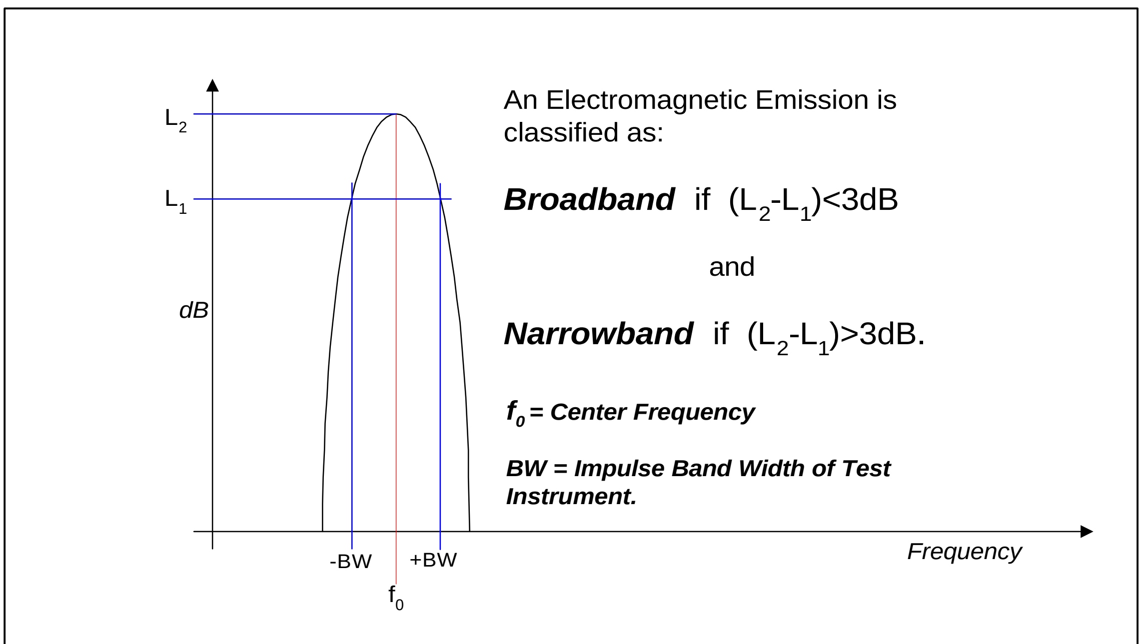
EMC Frequency Spectrum
Figure 3

The use of higher speed switching logic increases emissions from printed circuit boards. Also the use of devices with low operating voltages and currents, packaged more closely together, increases the potential for intra-system interference and reduced immunity (increased susceptibility).

Bandwidth

One cannot sufficiently classify EMI disturbances in terms of frequency content only. The character of the signal also needs to be examined. The character of the interference signal can be described as either *narrowband or broadband* in nature.

Classification according to bandwidth is determined from the ratio of the EMI signal to a reference bandwidth. This ratio can be given in a manner derived from both the measuring receiver bandwidth and the characteristics of the disturbance signal. Therefore, an electromagnetic emission is classified as broadband if while tuning the measuring bandwidth over a range of two impulse bandwidths (IBW) around its center frequency, a change in peak response of 3 dB or less is detected. If a change of 3 dB or more is depicted the signal would be determined to be narrowband. Therefore, bandwidth is a function of the measuring receiver as depicted in figure 4 below.



EMI Bandwidth
Figure 4

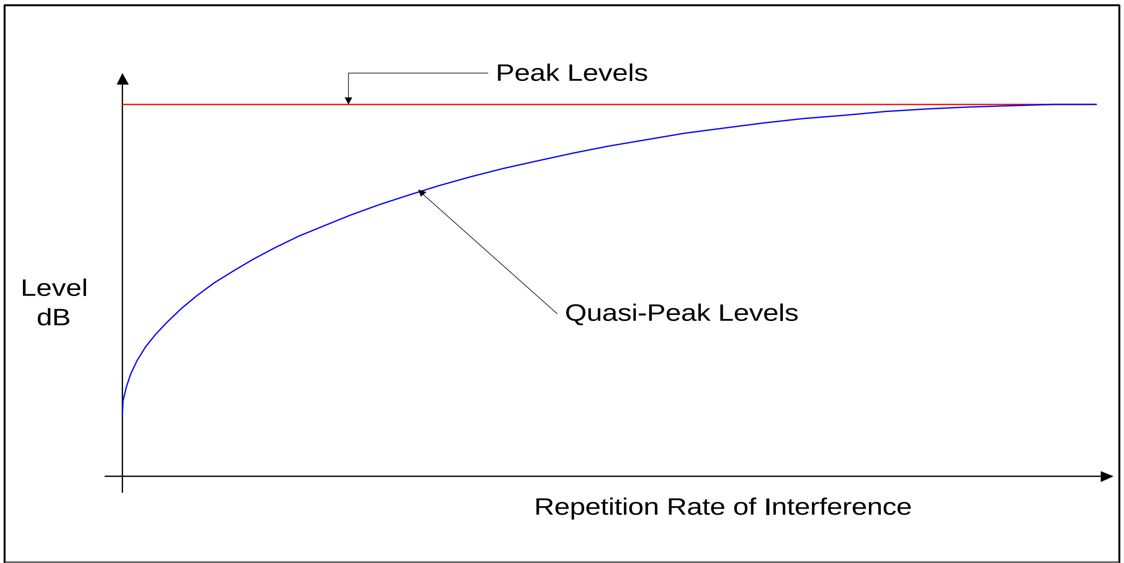
Unintentional radiating sources usually exhibit wide bandwidths (broadband noise) and usually have high magnitudes. Deliberate noise sources like cellular telephone, Radio and TV transmitters, etc., will generate narrowband signals. Examples of broadband noise sources are typically brush motors, inverter circuits, SCR circuits and more.

Single frequency signals can be described as narrowband. A sine wave is a pure tone and contains only one single frequency. However, a square wave such as produced by a digital switching circuit or pulse, contains more than one frequency, comprising of the fundamental frequency and harmonics. Each harmonic, therefore, represents a narrowband source.

Military Standards and some of the older CISPR standards referred to test procedures and limits using Narrowband and Broadband detectors. However, the EU **European Norm (EN)** standards specify the use of Quasi-peak and Average detectors for measuring EMI levels.

A Quasi-peak detector has specified electrical time constants which, when regularly repeated identical pulses are applied to it, delivers an output voltage which is a fraction of the peak value of the pulses, this fraction increasing towards unity as the pulse repetition rate is increased.

The quasi-peak EMI detection system is probably the fairest way of assessing interference as it is based on the annoyance factor of the interfering signal. The higher the repetition rate of the interfering signal (i.e. the higher the annoyance factor) the longer and higher the detector stays charged, therefore, the higher the level recorded. As the repetition rate of the interfering signal increases, the quasi-peak level approximates the peak level. This is shown in figure 5 below.



Quasi-Peak vs. Peak Detector
Figure 5

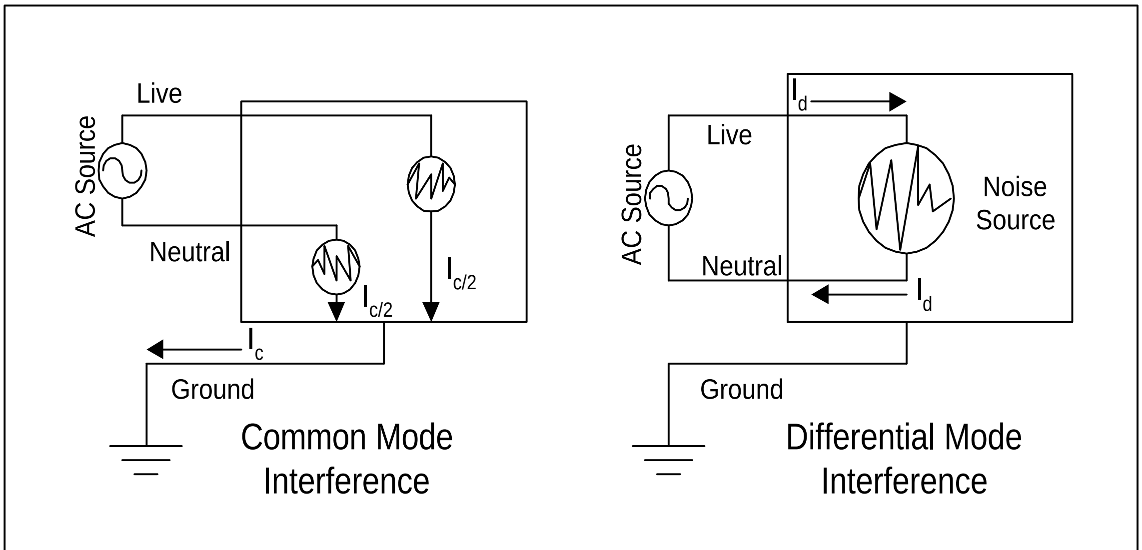
The Average detector gives the average value of the envelope of an applied signal. The average value must be taken over a specified time interval. A constant signal like a clock signal will be measured with an average detector. Typically, a broadband signal will be detected as quasi-peak and a narrowband signal as average.

Common Mode and Differential Mode Interference

Electromagnetic disturbances can appear in the form of **Common-Mode (CM)** and **Differential-Mode (DM)** voltage and current components. Differential mode also called *symmetrical noise or interference* occurs when noise currents travel between live and neutral (or return). The differential mode voltage components are measured between the phase conductors. Differential mode signals are usually used to convey the desired information and do not usually cause that much interference as the EMI fields generated by differential currents oppose each other (180^o out of phase) causing a cancellation effect.

Common mode signals, on the other hand are usually the major source of EMI from power and transmission (all I/O) cables. They cause the cables to behave as monopole antenna. These currents flow from the phase and neutral conductors to ground (earth). The circuit for the common mode component is completed by the stray impedance (capacitance) to ground.

When solving EMI problems it is important to distinguish between differential mode and common mode interference.

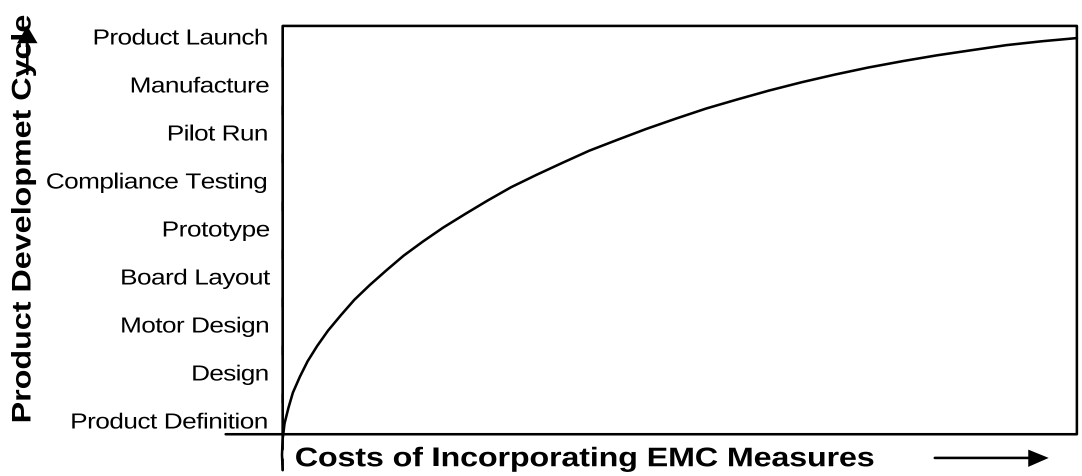


Common Mode and Differential Mode Interference
Figure 6

DESIGNING FOR EMC COMPLIANCE

Costs of Incorporating EMC

What are the costs of incorporating Electromagnetic Compatibility (EMC) into the product? The curve in figure 7 below shows that the earlier EMC is incorporated into the product development cycle, the lower the cost impact. Laying out a printed circuit board and designing a motor with good EMC characteristics is far less costly than trying to find an EMC solution when the product is ready for launch and has failed its compliance tests.



Costs of Incorporating EMC
Figure 7

Designing Appliances for EMC

In previous years, most appliances contained a motor and perhaps a triac for speed control. Today's appliances however can contain some very sophisticated electronic controls. Many appliances are packaged in plastic housings, making the control of radiated emissions even more difficult. In addition the EU EMC regulations have also changed (and are changing) and appliances containing electronic controls now need to comply with immunity as well as emission standards. This has created a new challenge for the appliance manufacturer trying to market his product in the EU.

The product family EU harmonized standard used to assess EMI emission levels for appliances, portable tools and similar equipment is EN55014-1. Conducted emissions are measured from 150 kHz to 30 MHz and radiated emissions from 30 MHz to 300 MHz. The power cable from an appliance tends to act as an antenna for the higher frequencies. Therefore, radiated emissions are measured along the power cord with an absorbing clamp. The interference levels are measured with a quasi-peak and average detector.

Appliances containing electronic controls also have to comply with the immunity standards in accordance with the product family EU harmonized standard EN55104-2. The tests for immunity compliance are comprised of electrostatic discharge (EN61000-4-2), fast transients (EN61000-4-4), injected currents up to 230 MHz (EN61000-4-6), surges (EN61000-4-5) and voltage dips and interruptions (EN61000-4-11).

The EMC development cycle for an appliance is somewhat iterative in that solutions for conducted emissions usually influence the radiated emissions levels and frequencies. In order to successfully design an EMC solution during the development cycle of the product, a number of questions have to be answered. For purposes of illustrations let us take as an example a double insulated (two-wire) appliance that contains a brush motor, an electronic speed control and an electronic timer.

EMI from the Brush Motor

Let us first examine the brush motor. EMI from brush motors are generally common mode and broadband in nature. The highest interference levels can usually be found in the low end of the conducted emission frequency range (typically from 150 kHz to 1 MHz). The electrical noise source of the motor is the brush/commutator interaction. Attention should be paid to the number of commutator bars and to the selection of brush grades as these can play a significant role in the level of interference generated. Certain field winding configurations can help reduce the radiated interference levels as the field coils act as chokes to the higher frequencies. Care should be taken to leave sufficient space for an EMI filter as improving the EMI characteristics of the motor will not necessarily eliminate the need for filtering.

EMI from the Triac Speed Control

SCR's and Triacs are used to regulate the voltage and therefore the current flowing into a load from an AC supply. The RMS voltage supplied to the motor can be controlled by the firing angle of the triac. These devices can generate very high levels of EMI towards the line and load. The maximum level of interference is generated when the phase angle is around 90^o (usually around half speed) when the voltage is chopped at its peak. The interference generated is broadband and differential mode in nature with the highest levels at the low end of the frequency spectrum (from 150 kHz to 750 kHz). The use of zero cross over detection triac firing reduces the levels of interference.

EMI from the Electronic Timer

Appliances containing clocks, oscillators or any electronic switching devices will generate EMI emissions. Clocks are usually the primary culprits of high frequency emissions. They tend to be designed (or overdesigned) with very fast rise times. To reduce the potential for high levels of EMI radiation, the clock rise time and power level should be reduced as much as is practical. Select a clock with a fast enough rise time to do the job, not the fastest rise time available.

The traces on the pc board are the medium of propagation of EMI. These emissions, which radiate from the traces, are generally in the form of common mode noise. The typical trace inductance on a pc board is 7.5nH per cm. At 100 MHz this translates to an impedance of approximately 5Ω per cm. Therefore, the longer the pc board traces the longer the antenna and the higher the potential for EMI radiation.

There are a number of techniques available to the design engineer to reduce the potential for high levels of EMI from pc boards. The following is a very brief list of basic good EMC practices to follow when designing pc board circuits.

- Make use of multilayer pc boards (wherever possible) with large ground planes.
- Use decoupling capacitors (disc ceramic) with short lead lengths from the IC's supply to ground, keeping the capacitor close to the IC. This provides a low impedance path for high frequency unwanted signals.
- Keep trace lengths as short as possible. This limits the trace impedance and the antenna effect for common mode signals.
- Carefully select components to minimize the potential of EMI.

EMI Filtering

If an EMI filter is deemed necessary, an application specific designed filter will reduce cost and complexity by eliminating extraneous components. Should there exist a lack of in-house EMC expertise and capability it is advisable for the design engineers to confer with an EMI filter manufacturing company who can assist with subassembly testing and the development of the most cost effective overall EMC solution. Tansient voltage suppressors (MOV's), EMI filters and careful selection of components and board layout will also help eliminate most immunity problems.

General

Experience indicates that for most electrical product manufacturers, EMC is not a core competency. Their core is usually made up of electrical, mechanical, ergonomical and motor engineers. Positions of compliance or safety engineer also exist but these are rarely EMC specialists. Many manufacturers focus their design effort on the domestic market, which presently does not have rigorous EMC requirements. To satisfy European Union customers, manufacturers tend to modify already existing product designs by upgrading the components to 250 Volts and replacing the power cord. EMC comes back to haunt them when the product is submitted for compliance testing and it fails. Thus, any old quick EMI fix is found, regardless of cost or ease of assembly.

EMC, not usually being a core competency, is a perfect candidate for outsourcing. However, manufacturers do not always select their EMC sources carefully as they do their motor suppliers for example. Lack of EMC knowledge is the reason. Hopefully the information in this article has given the readers the necessary EMC knowledge to make informed decisions that will help them meet the challenge of complying with the EMC Directive as cost effectively as possible.