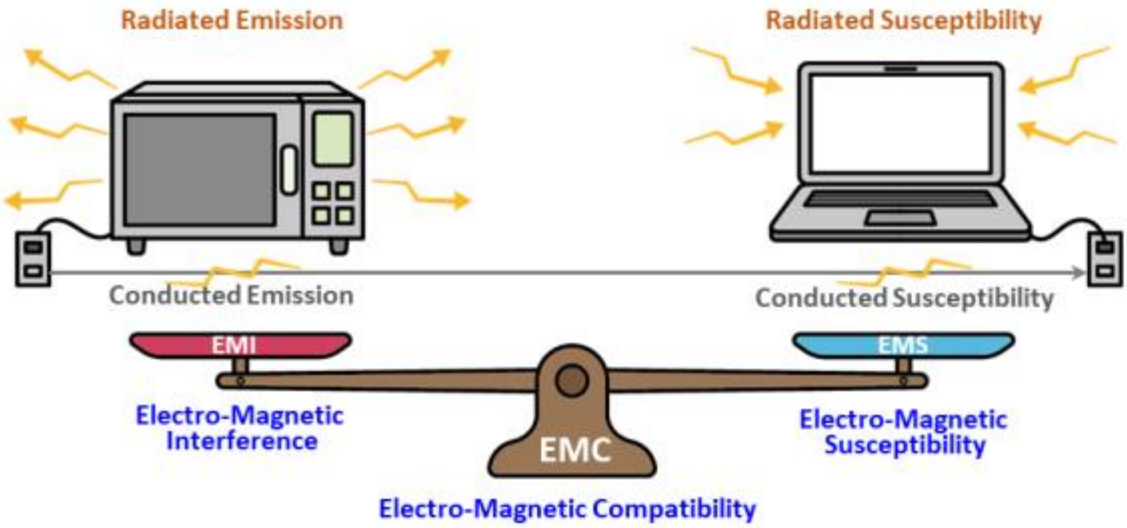
INTORDUCTION

TO

EMI-EMC



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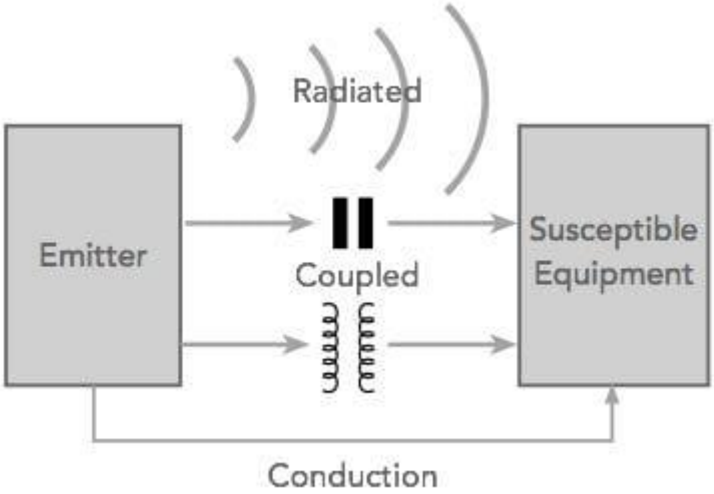
What is EMC?

Electromagnetic compatibility, EMC is the concept of enabling different electronics devices to operate without mutual interference - Electromagnetic Interference, EMI - when they are operated in close proximity to each other.

All electronics circuits have the possibility of radiating of picking up unwanted electrical interference which can compromise the operation of one or other of the circuits.



EMC is defined as the ability of devices and systems to operate in their electromagnetic environment without impairing their functions and without faults and vice versa.

Electromagnetic compatibility, EMC ensures that operation does not influence the electromagnetic environment to the extent that the functions of other devices and systems are adversely affected.

EMC awareness build-up

In the early days of electronics comparatively few items of electronics equipment were in use. However today the number of electronics items in everyday has vastly risen. Some of these transmit signals, while many others are sensitive receivers. Others may utilise digital electronics systems that could be falsely triggered by transient signals. These any many more examples may EMC a crucial element of any electronics design.

In the early days of electronics systems, pops, bangs and general noise received by radios were taken as being part of "experience" of listening to a radio - even if they were man-made from other local electrical equipment.

Some of the first major concerns of the effects of electrical interference on electronics systems arose from military applications. After the Second World War, with the rise in importance of nuclear weapons, the electronic pulse generated by an explosion and its effect on equipment became a concern. Also, the effects of high powered radar systems on equipment were also a concern.

Later the risks to electronics equipment associated with ESD became visible. Not only did these damage the electronics equipment, but they could also set false triggers.

During the 1970s the use of logic circuitry grew rapidly, and with this the switching speeds increased. The opened up these circuits to the effects of EMI, and realisation grew of the need for EMC precautions to be incorporated into the design if these items were to work satisfactorily in the real world.

As a result of this growing realisation, many nations became aware of EMC as a growing problem. Some started to issue directives to the manufacturers of electronic equipment, defining standards that the equipment should meet before equipment could be sold. The European Community was one for the first areas where EMC requirements were enforced. While many were sceptical at first, the introduction of EMC standards has raised standards and enabled most types of equipment to operate alongside each other without interference. This has been particularly important with the rapid growth in the use of mobile phones.

EMC basics

The aim of employing EMC measures is to ensure that a variety of different items of electronics equipment can operate in close proximity without causing any undue interference.

The interference that gives rise to impaired performance is known as Electromagnetic Interference, EMI. It is this interference that needs to be reduced to ensure that various items of electrical equipment are compatible and can operate in the presence of each other.

There are two main elements to EMC:

- **Emissions:** The EMI emissions refer to the generation of unwanted electromagnetic energy. These need to be reduced below certain acceptable limits to ensure they do not cause any disruption to other equipment.
- **Susceptibility & immunity:** The susceptibility of an item of electronics to EMI is the way it reacts to unwanted electromagnetic energy. The aim of the design of the circuit is to ensure a sufficiently high level of immunity to these unwanted signals.

Electromagnetic interference, EMI

Electromagnetic interference, EMI is the name given to the unwanted electromagnetic radiation that causes potential interference to other items of electronics equipment.

There are many ways in which electromagnetic interference can be carried from one item of equipment to another. Understanding these methods is a key to mitigating the effects of the electromagnetic interference.

EMI can be divided into two categories:

- **Continuous interference:** The continuous interference is often in the form of a radio signal or oscillation that is maintained. It could be from an unscreened oscillator, or it may be in the form of wideband noise.
- **Impulse interference:** This form of interference consists of a short impulse. It may arise from an electrostatic discharge, lightning, or a circuit being switched.

Apart from understanding the form of the interference, it is also necessary to know how the interference is travelling from the transmitting device to the receiving device. Unfortunately this is not always easy to discover as many of the paths are difficult to define. However good initial design alleviates many problems.

EMC standards

With the growing awareness and need to maintain high standards of electromagnetic compatibility many standards have been introduced to help manufacturers meet the levels they need to maintain full electromagnetic compatibility.

Many years ago, the levels of EMC were low and interference often occurred - taxis driving past a house whilst using their radio telephone were quite likely to disrupt the operation of a television, and there were many other instances. As a result, it became necessary to introduce EMC standards to ensure the required levels of compatibility were attained.

EMC is now an integral part of any electronics design project. With standards now implemented and enforced across the world, any new product needs to meet and have been tested to ensure it meets the relevant EMC standards. While this presents an additional challenge to the electronics design engineer, it is essential that good EMC practices have been employed and that the EMC performance of the product is sufficient to ensure it operates correctly under all reasonable scenarios.

There are many forms of electromagnetic interference, EMI that can affect circuits and prevent them from working in the way that was intended. This EMI or radio frequency interference, RFI as it is sometimes called can arise in a number of ways, although in an ideal world it should not be present.

EMI - electromagnetic interference can arise from many sources, being either man made or natural. It can also have a variety of characteristics dependent upon its source and the nature of the mechanism giving rise to the interference.

By the very name of interference given to it, EMI is an unwanted signal at the signal receiver, and in general methods are sought to reduce the level of the interference.

Types of EMI - Electromagnetic Interference

EMI - Electromagnetic Interference can arise in many ways and from several sources. The different types of EMI can be categorised in several ways.

One way of categorising the type of EMI is by the way it was created:

- **Man-made EMI:** This type of EMI generally arises from other electronics circuits, although some EMI can arise from switching of large currents, etc.
- **Naturally occurring EMI:** This type of EMI can arise from many sources - cosmic noise as well as lightning and other atmospheric types of noise all contribute.

Another method of categorising the type of EMI is by its duration:

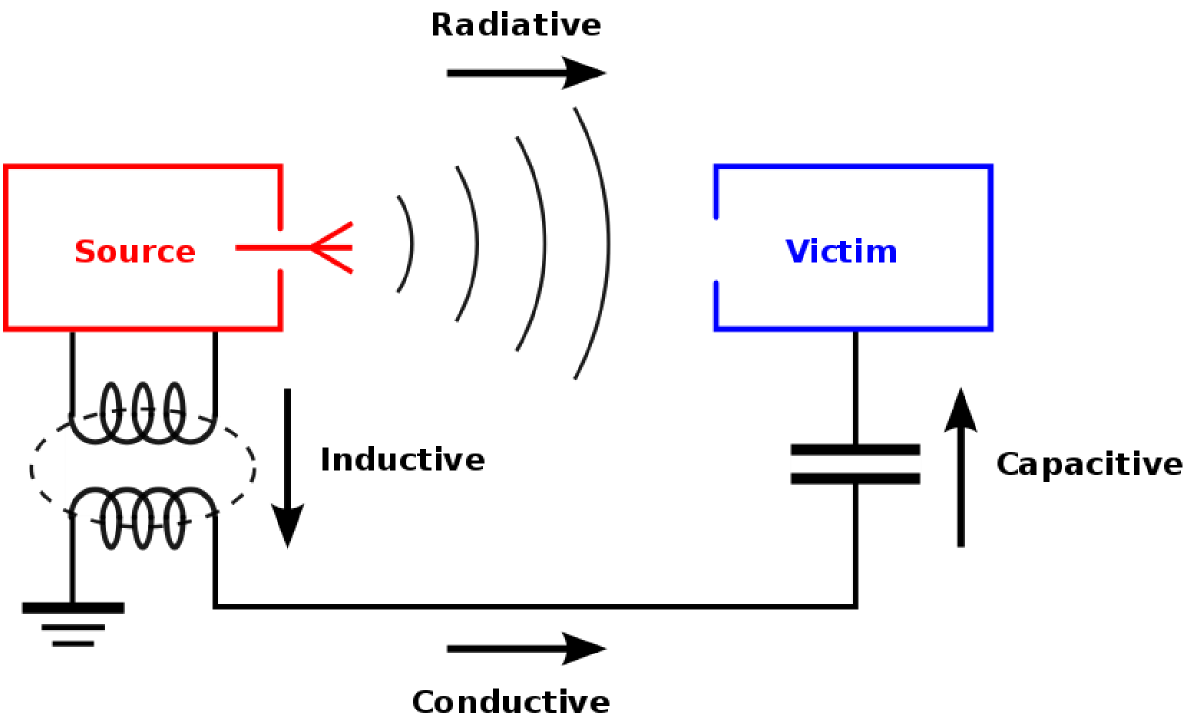
- **Continuous interference:** This type of EMI generally arises from a source such as a circuit that is emitting a continuous signal. However, background noise, which is continuous may be created in several ways, either manmade or naturally occurring.
- **Impulse noise:** Again, this type of EMI may be man-made or naturally occurring. Lightning, ESD, and switching systems all contribute to impulse noise which is a form of EMI.

It is also possible to categorise the different types of EMI by their bandwidth.

- **Narrowband:** Typically, this form of EMI is likely to be a single carrier source - possibly generated by an oscillator of some form. Another form of narrowband EMI is the spurious signals caused by intermodulation and other forms of distortion in a transmitter such as a mobile phone of Wi-Fi router. These spurious signals will appear at different points in the spectrum and may cause interference to another user of the radio spectrum. As such these spurious signals must be kept within tight limits.
- **Broadband:** There are many forms of broadband noise which can be experienced. It can arise from a great variety of sources. Man-made broadband interference can arise from sources such as arc welders where a spark is continuously generated. Naturally occurring broadband noise can be experienced from the Sun - it can cause sun-outs for satellite television systems when the Sun appears behind the satellite and noise can mask the wanted satellite signal. Fortunately, these episodes only last for a few minutes.

EMI coupling mechanisms

There are many ways in which the electromagnetic interference can be coupled from the source to the receiver. Understanding which coupling method brings the interference to the receiver is key to being able to address the problem.



Electromagnetic interference coupling mechanisms.

1. **Radiated:** This type of EMI coupling is probably the most obvious. It is the type of EMI coupling that is normally experienced when the source and victim are separated by a large distance - typically more than a wavelength. The source radiates a signal which may be wanted or unwanted, and the victim receives it in a way that disrupts its performance.
2. **Conducted:** Conducted emissions occur as the name implies when there is a conduction route along which the signals can travel. This may be along power cables or other interconnection cabling.

The conduction may be in one of two modes:

- **Common mode:** This type of EMI coupling occurs when the noise appears in the same phase on the two conductors, e.g. out and return for signals, or +ve and -ve for power cables.
- **Differential mode:** This occurs when the noise is out of phase on the two conductors.

The filtering techniques required will vary according to the type of EMI coupling experienced. For common mode lines are filtered together. For differential mode they may be filtered together.

3. **Coupled:** What is normally termed coupled EMI can be one of two forms, namely capacitive coupling and magnetic induction.

- **Capacitive coupling:** This occurs when a changing voltage from the source capacitively transfers a charge to the victim circuitry.
- **Magnetic coupling:** This type of EMI coupling exists when a varying magnetic field exists between the source and victim - typically two conductors may run close together (less than λ apart). This induces a current in the victim circuitry, thereby transferring the signal from source to victim.

By determining the form of coupling that exists and the way in which it is reaching the victim, it may prove to be that the most effective method of reducing the EMI is by putting measures in place to reduce the coupling and reduce the level of interference to an acceptable level.

Electromagnetic interference, EMI is present in all areas of electronics. By understanding the source, the coupling methods and the susceptibility of the victim, the level of interference can be reduced to a level where the EMI causes no undue degradation in performance.

In order to ensure that EMC is not a problem for the wide variety of electronics equipment available today, many EMC standards are used, and these are often supported by EMC legislation to ensure that all goods entering an area conform to the required standards.

Evolution of EMC standards & legislation

The basic awareness of the possibilities of interference between various forms of electronics equipment had been around for many years. However, the relatively limited use of electronics by today's standards meant that little was undertaken in terms of legislation regarding standards.

Some of the first EMC standards and legislation were introduced in 1979. The Federal Communications Commission, FCC in the USA imposed legal limits on the electromagnetic emissions from all digital equipment. These limits were imposed because of the growing availability of digital systems including small calculators and forms of digital equipment that were interfering with wired and radio communications and broadcast systems.

A few test methods were defined to support this EMC legislation.

A further major step forwards was taken in the 1980s by the European Community. They introduced what was termed a new approach to standardising EMC requirements to enable trade of electronics equipment to be undertaken more freely.

One of the major elements of this was the EMC Directive - 89/336/EC. This EMC standard applied to all equipment that was to be placed on the market of used within the EC. The scope was broad, and the EMC Directive encompassed all equipment that was "liable to cause electromagnetic disturbance or the performance of which is liable to be affected by such disturbance."

The EMC Directive from the EC was ground-breaking in terms of EMC standards and legislation as it was the first time that limits had been placed on the immunity of the equipment to interference as well as its emissions. As such the EMC Directive recognised both elements of EMC - operating equipment harmoniously is not just a matter of reducing unwanted emissions as wanted emissions can also cause interference.

The EMC Directive has moved onwards and is now a well-established EMC standard. It has been seen as a success, although there are recognised significant costs associated with it. As a result of its success, many other countries have implemented similar EMC legislation, often utilising the same EMC standards as those employed by the EC. This gives harmonious standards and figures to meet around the globe, thereby allowing for economies of scale.

Common EMC standards

There are several common EMC standards that are widely used. Some of these standards also include other elements apart from just the EMC performance.

COMMON EMC STANDARDS

ARENA	STANDARD	DETAILS
Aerospace	DO-160	Aircraft EMC requirements
Aerospace	SAE ARP5412B	Aircraft lightning environment and related test waveforms
Aerospace	SAE ARP5416A	Aircraft lightning test methods
Automotive	SAEJ1113	General automotive EMC
Commercial	ANSI C63.4	Methods of measurement
Commercial	CISPR 11	ISM equipment EN 55011
Commercial	CISPR 16	Methods of measurement
Commercial	CISPR 22	ITE equipment EN 55022
Commercial	FCC Part 15B	ITE equipment
Commercial	IEC 61000-3-2	Harmonics
Commercial	IEC 61000-3-3	Flicker
Commercial	IEC 61000-4-2	Electrostatic Discharge, ESD
Commercial	IEC 61000-4-3	Radiated immunity
Commercial	IEC 61000-4-4	Electrically Fast Transient
Commercial	IEC 61000-4-5	Surge (lightning)
Commercial	IEC 61000-4-6	Conducted immunity
Commercial	IEC 61000-4-8	Magnetic immunity
Commercial	IEC 61000-4-11	Voltage dips, interrupts & variations
Medical	IEC 60601-1-2	Medical products
Military	MIL STD 461F	EMC test requirements

CISPR 11 is a widely used international standard for electromagnetic compatibility within Europe for electromagnetic emissions or disturbances from Industrial, Scientific and Medical, ISM, Equipment. CISPR 11 is maintained by CISPR: the International Special Committee on Radio Interference.

CISPR 11 applies to a very wide variety of equipment including everything from Wi-Fi systems, and microwaves through to arc welders, all of which fall into the industrial, scientific and medical category that can use the ISM license free bands like 2.4 GHz.

CISPR applicability

Compliance with CISPR 11 gives a partial presumption of conformity with the European EMC Directive, 2004/108/EC.

The CENELEC equivalent of CISPR 11, EN 55011 is an emission only standard covering radiated and conducted emissions. Most products will also require assessment to immunity standards, such as: EN 61326-1: Electrical equipment for measurement, control, and laboratory use; or EN 61000-6-2: Generic Standards Immunity for industrial environments.

CISPR 16 is a series of fourteen publications specifying equipment and methods for measuring disturbances and immunity to them at frequencies above 9 kHz.

CISPR 16 is split into four distinct parts with an overall number of fourteen different elements.

CISPR 16 basics

The CISPR standards and specifications are issued by the International Special Committee on Radio Interference, CISPR which is the organisation used for setting EMC standards in Europe. CISPR 16 specifies all that is needed to undertake the EMC tests in the CISPR series.

It defines the characteristics and performance of equipment for the measurement of radio disturbance voltages and currents in the frequency range 9 kHz to 1 GHz.

CISPR 16 has the status of a basic EMC publication. The specification includes details of the ancillary apparatus needed for artificial mains networks, current and voltage probes and coupling units for current injection on cables.

CISPR 16-1

This consists of five parts which specify voltage, current and field measuring apparatus.

CISPR 16 PART 1

CISPR 16 PART NUMBER	DETAILS
Part 1-1	Measuring apparatus
Part 1-2	Ancillary equipment - Conducted disturbances
Part 1-3	Ancillary equipment - Disturbance power
Part 1-4	Ancillary equipment - Radiated disturbances
Part 1-5	Antenna calibration test sites for 30 MHz to 1 000 MHz

CISPR 16-2

CISPR 16-2 consists of five parts which specify the methods for measuring high-frequency EMC phenomena. It addresses both EMC disturbances and immunity.

CISPR 16 PART 2	
CISPR 16 PART NUMBER	**DETAILS**
Part 2-1	Conducted disturbance measurements
Part 2-2	Measurement of disturbance power
Part 2-3	Radiated disturbance measurements
Part 2-4	Immunity measurements
Part 2-5	In situ measurements for disturbing emissions produced by physically large equipment

CISPR 16-3

CISPR 16-3 is basically a technical report rather than a standard and it contains specific technical reports and information on the history of CISPR.

CISPR 16-4

CISPR 16 Part 4 consists of five parts and contains information related to uncertainties, statistics, and limit modelling.

CISPR 16 PART 1	
CISPR 16 PART NUMBER	**DETAILS**
Part 4-1	Uncertainties in standardized EMC tests
Part 4-2	Uncertainty in EMC measurements
Part 4-3	Statistical considerations in the determination of EMC compliance of mass-produced products
Part 4-4	Statistics of complaints and a model for the calculation of limits
Part 4-5	Conditions for the use of alternative test methods

CISPR 22 is a widely used standard for electromagnetic compatibility within Europe for Information Technology Equipment, ITE. CISPR 22 is maintained by CISPR: the International Special Committee on Radio Interference

There is also another related standard: EN 55022 which is the CENELEC standard. EN 55022 is a modified derivative for CISPR 22 and as a result both standards are used within the industry.,

CENELEC is the European Committee for Electrotechnical Standardisation and has produced EN 55022 based upon the original CISPR 22 standard.

What is CISPR 22?

CISPR 22 is the CISPR standard for Information Technology Equipment-Radio Disturbance Characteristics-Limits and Methods of Measurement.

CISPR 22 has been adopted for use by most members of the European Community.

CISPR 22 & FCC

With CISPR 22 being widely used within the European Community, it is often necessary to relate it to other standards, the main one being the FCC, Federal Communications Commission in the USA. Here the FCC Part 15 standard is used.

To ensure that either standard can be used to certify digital electronic equipment, FCC Part 15 and CISPR 22 have been made to be relatively harmonious, although there are a few differences.

CISPR 22 differentiates between Class A and Class B equipment, and it gives figures for conducted and radiated emissions for each class. In addition, CISPR 22 requires certification over the frequency range of 0.15 MHz to 30 MHz for conducted emissions. On these points there are differences between CISPR 22 and the FCC Part 15. Also, CISPR 22 has no specified limits for frequencies above 1.0 GHz, and CISPR limits are provided in dBµV, while the FCC limits are specified in µV which means that a simple conversion is required for direct comparisons.

In terms of similarities the conducted and radiated emission limits specified in CISPR 22 and FCC Part 15 are close to each other, i.e. within a few dB of each other over the detailed frequencies. In this way it is possible to meet both standards easily for the certification process.

Summary of CISPR 22 limits

The tables below give a summary of the field strength limits for conducted and radiated emissions within the per CISPR 22 standard.

CISPR 22 CLASS A CONDUCTED EMI LIMIT

FREQUENCY OF EMISSION (MHZ)	CONDUCTED LIMIT (DBMV)	
	Quasi-peak	Average
0.15 - 0.50	79	66
0.50 - 30.0	73	60

CISPR 22 CLASS B CONDUCTED EMI LIMIT

FREQUENCY OF EMISSION (MHZ)	CONDUCTED LIMIT (DBM;V)	
	Quasi-peak	Average
0.15 - 0.50	66 to 56	56 to 46
0.50 - 5.00	56	46
5.00 - 30.0	60	50

CISPR 22 CLASS A 10-METRE RADIATED EMI LIMIT	
FREQUENCY OF EMISSION (MHZ)	FIELD STRENGTH LIMIT (DBMV/M)
30 - 88	39
88 - 216	43.5
216 - 960	46.5
above 960	49.5

CISPR 22 CLASS B 3-METRE RADIATED EMI LIMIT	
FREQUENCY OF EMISSION (MHZ)	FIELD STRENGTH LIMIT (DBMV/M)
30 - 88	40
88 - 216	43.5
216 - 960	46.0
above 960	54.0

What is often called just FCC Part 15 is actually Code of Federal Regulations, Title 47, Part 15, 47 CFR 15. Title 47 of the Code of Federal Regulations in the USA regulates everything from spurious emissions to unlicensed low-power broadcasting. Part 15 of the FCC Title 47 is often just called FCC part 15 and it relates to EMC.

The FCC Part 15 rules and regulations have been designed to align with the European CISPR regulations. There are some differences but in general the two sets of standards align on the major features.

FCC Part 15 basics

The scope of FCC Part 15 is split into three sections as follows:

FCC Part 15A: This section sets out the regulations under which an intentional, unintentional, or incidental radiator may be operated without an individual license. FCC Part 15A also contains the technical specifications as well as the administrative requirements and other conditions relating to the marketing of FCC Part 15 devices.

FCC Part 15B: FCC Part 15B covers the operation of an intentional or unintentional radiator that is not in accordance with the regulations in this part must be licensed according to the provisions of section 301 of the US Communications Act of 1934.

FCC Part15 C: Unless specifically exempted, the operation or marketing of an intentional or unintentional radiator that is not in compliance with the administrative and technical provisions in this part, including prior FCC authorization or verification, as appropriate, is prohibited under section 302 of the US Communications Act of 1934, There are two classes of device for FCC Part 15:

- **Class A digital device:** Within FCC Part 15, a Class "A" digital device is one that is marketed for use in a commercial, industrial, or business environment.
- **Class B digital device:** Within FCC Part 15, a Class "B" digital device is one that is marketed for use in a residential or domestic environment. Examples of devices in this category may be personal computers, calculators, and similar electronic devices that are marketed for use by the general public.

Good EMC design techniques are not too difficult to implement if they are introduced at the earliest stages of design. If modifications need to be made later in the design to meet EMC requirements, then it becomes much harder.

EMC design from the earliest stages of the project follows some straightforward and common-sense design approaches.

EMC design - some basics

When considering any project, EMC design criteria are important: any electronic circuit that has signals that change in level will tend to radiate some power as any interconnections, and wires will act as radiating antennas, however short they may be. Similarly, circuits will tend to pick up radiated signals from other transmitters whether these sources are transmitting intentionally or not.

EMC design also needs to take on board any capacitive and inductive coupling along with unwanted emissions that may be conducted along common lines that go to both items of equipment. This can include earth lines as well.

These Electromagnetic Interference, EMI, problems can prevent adjacent pieces of electronics equipment working alongside one another. With the vast growth in the usage of electronic equipment, this problem of Electromagnetic Compatibility, EMC has become a particularly important topic.

As a result, it is necessary to design for EMC from the outset of a new electronics development project and implement the various design techniques for EMC into the whole concept of the product. Only by taking account of the design for EMC aspects at the concept stages of a development, can any precautions be implemented correctly.

In years gone by transmitters might prevent local domestic televisions from displaying their picture. In the worst case the whole picture could disappear, or there may be some patterning of the picture. With these and many other examples of the results of poor EMC regulation becoming more widespread, it became necessary to improve matters. Now with modern electronic equipment it is possible to operate mobile phones and other wireless devices near almost any electronics equipment with little or no effect. This has come about by ensuring that equipment does not radiate unwanted emissions and making equipment less vulnerable to radio frequency radiation. In this way, these aspects of design for EMC have paid major dividends in today's world where there is a huge amount of electronic equipment being used.

Design for EMC compliance

When designing an electronic circuit card, it is necessary to take several precautions to ensure that its EMC performance requirements can be met. Trying to fix the EMC performance once the circuit has been designed and built will be far more difficult and costly. Accordingly, there are several areas that can be address during the design to ensure that the EMC performance is optimised:

- Circuit design for minimum radiation
- EMC filters
- Circuit partitioning
- Grounding
- Screened enclosure.
- Screened lines and cables.

By adopting these precautions, the EMC performance of the circuit can be greatly enhanced. However, it will still need to undergo EMC testing to ensure that it meets the required performance.

EMC circuit design for minimum radiation

One of the chief areas that needs to be borne in mind for EMC / EMI compliance is the RF radiated emissions arising from connecting cables and the susceptibility to receiving interference. It is found that they form the major coupling path for interference in any product. Often these cables need to carry high frequency signals, possible data, and this can present some challenges in terms of improving their EMC / EMI performance.

Any cable will receive and radiate signals, especially when it approaches a quarter wavelength, or odd multiple thereof because it forms a resonant circuit. However even when the cable does approach these lengths, electromagnetic compatibility, EMC can be a problem.

One solution is to filter the cables entering and leaving the unit. While this does reduce the level of EMI, it may also degrade the performance of the circuit. If high speed data needs to be carried, then any sharp edges will be removed by the filters, and in the worst case, the signal may be attenuated to such a degree that the system does not work. Thus, a careful balance may need to be made for the filter between the equipment performance and the electromagnetic compatibility, EMC requirements.

In these circumstances the signals can be carried in a differential format. The signal cables can then be constructed as a twisted pair and could even be screened. In this way the high frequency signal can be carried, but its susceptibility to radiation and reception is reduced, because anything received will appear on both lines and cancelled out. Additionally, radiation does not occur for the same reason.

EMC design: filters

The possibility of introducing EMC filters has already been mentioned. It can form a useful tool for the EMC engineer to use in many instances. EMC filters are particularly useful for lines that only carry low frequency signals. Power input cables, or other lines that carry status voltages are particularly good candidates for filtering. Here EMC filters can remove any high frequency components, leaving the low frequency elements on the line that will not radiate much.

EMC filters should be placed at the entry point to the unit and should be tightly bonded to the chassis. In this way no signals can enter the unit and radiate into it prior to being removed by the filter.

EMC design: circuit partitioning

This element of the circuit design is important to ensure that the circuit can pass its EMC test. It must be accomplished at the very earliest stages of the design in view of the fact that it governs the whole topology of the circuit and the mechanical construction.

The first stage of the partitioning process is to segregate the circuit into EMC critical and non-critical areas. The electromagnetic compatibility, EMC critical areas are those areas which contain sources of radiation, or may be susceptible to radiation. These areas may include circuits containing high frequency circuitry, low level analogue circuits and high speed logic including microprocessor circuits.

The Non-critical EMC areas are those which contain areas that are unlikely to radiate signals or be susceptible to radiation. Circuits including linear power supplies (not switch mode power supplies), slow speed circuits and the like.

Once this action has been completed, the layout for the design can be undertaken. The critical or sensitive regions can be screened or and filters added as necessary at the interfaces to prevent EMI being radiated, or to protect these circuits from the effects of EMI.

By isolating the EMC critical areas, it is possible to add the relevant measures both at the initial stages of the design, or possibly later. Having an interface provides the possibility for optimising the overall performance to meet its EMC test. This may result in the addition of further filtering, screening, etc., or it may even enable cost reductions to be made if some of the measures are not required.

Grounding

The grounding scheme within a unit is of particular importance for its EMC performance. Poor grounding can lead to earth loops that can in turn lead to signals being radiated, or picked up within the unit and hence poor electromagnetic compatibility, EMC performance results.

To help ensure that the earth or grounding system works satisfactorily, it is worth bearing in mind its function. It can be said to be a path that enables a current to return to its source. It should obviously have a low impedance, and it should also be direct. Any loops, or deviations may give rise to spurious effects that can give rise to EMC problems.

Planning earth or grounding systems is not trivial. It is more challenging than it appears, but essential for a good EMC performance. Lengths must be kept to a minimum because above frequencies more than only a few kilohertz the impedance is dominated by inductance, and lengths of a few centimetres make a significant difference, even at low frequencies.

To overcome these effects, thick wires should be used if possible, and on printed circuit boards ground planes must be used. Critical tracks must be run above the ground plane, and they should be routed so that they do not encounter any breaks in the ground plane. Sometimes it is necessary to have a slot or break in a ground plane, and if this occurs a critical track must be routed over the plane, even if it makes it slightly longer.

These and other approaches can be adopted to ensure that the grounding system is able to reduce the EMC problems to a minimum. Considerable thought should be given to the grounding, as it may not be easy to change at a later time.

Screened Enclosure

Although screened enclosures may not be an option that is preferred from a cost viewpoint, placing the unit in a conductive enclosure that is grounded will significantly improve the performance. All filtering can then be undertaken at this interface and the conductive wall will provide a barrier to radiation, thereby improving both the emissions and susceptibility elements of the EMC performance.

Where cost and possibly aesthetics are important it is possible to spray the inside of cabinets with conductive paint, although the level of screening provided will not be nearly as good as if a fully conductive metal case is used. Where high levels of EMC performance are required care should be taken to choose a case where the continuity of the screen is not breached. The case should ideally be made of as few elements as possible. At each joint there will be the possibility of radiation passing through. Where joints to occur they should be as tight as possible and they should have good continuity between them.

Some metal cases using a prefabricated style of construction with anodised aluminium panels do not offer good EMC performance, although they are aesthetically more pleasing than some RF tight cases. A balance has to be made dependent upon the performance required and the EMC tests that need to be undertaken.

Screened Lines and Cables

When lines and cables need to pass into or out of a unit, the cables can be screened to prevent any radiation of the signals being carried or pick up of external signals. However, when screened cables are needed for electromagnetic compatibility EMC applications, the screen must be bonded to the equipment signal ground as soon as it enters the unit, otherwise unwanted signals may be radiated or picked up and this would compromise the EMC compliance.

The electromagnetic compatibility, EMC performance is of electronic equipment today is a great importance and as a result it is necessary to design for EMC. In order to enable the unit to pass its EMC testing and be placed on the market, it is necessary for it to conform to the directives and regulations in force. For a unit to be successful, it is necessary for it to be designed to provide a high level of electromagnetic compatibility, EMC performance and reduction of EMI.

In order that an item of electronics equipment can pass its EMC testing and gain its EMC compliance, it is necessary to incorporate various elements into the design. By designing the circuit to meet the electromagnetic compatibility, EMC requirements it is possible to significantly reduce the levels of unwanted signals entering and leaving the unit. One of the major ways in which this can be done is to use an EMC filter or a series of filters.

There are many ways in which EMC filters can be incorporated into a unit from a mechanical viewpoint. They may exist as standalone EMC filters to be fixed near to the extremities of the unit. They may be mounted on the edge of the electronics board. However, one popular method of incorporating an EMC filter into a unit is to incorporate the filter into the connector itself. This has many advantages in terms of convenience and performance. However, whatever the method used, a filter is often necessary if the electromagnetic compatibility, EMC requirements are to be met.

EMC filter methodology

Although circuits may be well screened to prevent any signal radiated or being picked up by the circuit itself, there are always interconnections to and from the electronics circuit. These wires themselves can conduct unwanted signals into and out of the unit. If the unit is to be able to meet its electromagnetic compatibility, EMC requirements and pass its EMC testing, it is necessary to reduce the levels of unwanted signals that can enter or leave the unit via its interconnections.

In order to enable the unwanted signals to be removed, EMC filters need to be placed in the various lines. The idea is that the interfering signals generally have a frequency above that of the signals normally travelling along the wire or line. By having what is termed a low pass filter as the EMC filter, only the low frequency signals are allowed to pass, and the high frequency interference signals are removed.

These EMC filters can be in one of a variety of formats. Often they may be as simple as a resistor or a ferrite placed around a wire or cable. For more exacting requirements, these EMC filters may need to be made up from a number of components. The EMC filters may categorised into two main types. One is where the unwanted energy is absorbed by the EMC filter. The other type of filter rejects the unwanted signal and in this case it is reflected back along the line. For EMC filtering applications, the absorptive type is preferred.

EMC filter application

When developing filters for use in electromagnetic compatibility, EMC applications, the EMC filters are nearly always low pass filters, although on occasions bandpass filters may be used. The reason for using low pass filters is that typically interfering signals, i.e. ones that are easier to pick up or radiate tend to be at higher frequencies. These can be filtered by allowing the low frequencies through and rejecting the high frequencies.

The cut-off point for the low pass filter used as the EMC filter has to be chosen so that it rejects the unwanted frequencies, but does not have any undue effect on the wanted signal. Unfortunately this choice is not always easy and it may require some degradation of the wanted signal.

The EMC filter placing is of importance. EMC filtering can be placed at any or every level of assembly between segregated areas of circuitry. EMC filters may be placed between segregated areas of a printed circuit board. They may be placed between different boards within a module or sub-assembly, and an EMC filter may be placed between different modules or subassemblies. However a particularly important place for EMC filters is between the equipment and its external environment. An EMC filter placed here is particularly effective as it will prevent unwanted signals even entering the equipment. Once they enter they are more difficult to contain.

EMC filter design

The EMC filter design is critical to the electromagnetic compatibility, EMC performance. The EMC filter must be capable of providing the required level of attenuation of the unwanted signals while allowing through the wanted signals. In addition to this the EMC filter design must match both the source and load impedances.

Typically for a high impedance circuit, a capacitor connected between the line and ground provides better results, while for low impedance circuits a series inductor placed within the line provides the best results. Often a single component like this designed to have a reactance with little effect at frequencies appropriate to the wanted signals, but a much higher effect at the higher frequencies of the unwanted signal can provide levels of attenuation of up to 30 dB or 40dB in some cases. To improve the performance of one of these basic filters, further components can be added to make multi-component EMC filters. However to give the required performance they must be configured correctly. One precaution to ensure that inductors face a low impedance sink or source and capacitors face a high impedance.

One of the key areas of designing a circuit with good EMC performance is that of the PCB design. PCB design for EMC can enable a circuit board to perform well in terms of its EMC performance, and to help there are a few basic guidelines that can be followed to provide good EMC performance. Although it is possible to utilise multiple layers to reduce the size of the PCB, when designing a PCB for good EMC performance, this not always the optimal route to take.

The PCB design for EMC performance may require coupling to be reduced. This may require signals to be kept apart, or the distance between some components to be increased. Although small PCBs with good EMC performance can be designed, care must be taken from the outset.

Multi-Layer PCB

PCB design for EMC: some basics

When looking at optimum EMC performance a four layer board is often regarded as a good balance between board layout and EMC performance. That said, many boards with more layers can achieve good EMC performance, but require very careful design to achieve the good EMC performance.

Ground planes improve EMC Performance

One technique that is particularly useful is to use one layer within the board as a ground plane.

Signal return paths are one of the most difficult issues to resolve in printed circuit boards. It can be difficult to route a ground return satisfactorily from each integrated circuit across other signal layers, etc.

The only satisfactory solution is to use a ground plane which provides a low inductance and low resistance common ground which can provides a method of providing a short lead length to ground. By having one of the layers in the PCB reserved for a ground plane, it is easy to provide a good path to ground for any signals.

For some sensitive areas it may be necessary to isolate the ground to prevent ground currents flowing cross that section of circuit. For example a sensitive section of circuit may need to have its ground isolated and have a single connection to earth especially if a higher power section close by may cause earth currents to flow across the more sensitive section.

Gridding to Create Ground Planes

In some PCBs that may have a limited number of layers, for example one where only two layers are available a technique referred to as gridding may be used to ensure good EMC performance. This technique is a close approximation to having a ground plane in a two-layer board comes from gridding the ground to reduce EMI radiation from the signal traces.

Essentially gridding operates by creating a network of orthogonal connections between traces carrying ground. Although the ground plane is not completely contiguous, it sufficiently emulates the ground plane that is used to provide EMC improvements of a four or more layer board by providing a ground return path under each of the signal traces and lowers the impedance between the main ICs and the voltage regulation area.

Gridding is achieved by a process of expanding any ground traces and using ground-fill patterns. The aim is to create a network of connections to ground across the PCB. The gridding is achieved by expanded the ground lines to fill up as much of the empty PCB space as possible. Then, all the remaining empty space is filled with ground.

In this way as much of the available PCB space is filled with the ground grid as possible whilst still allowing connections to be made on the layer.

PCB Zoning

Creating different zones on a PCB is another useful design technique to improve EMC and general noise.

PCB zoning is essentially a process of planning where the general location of components for different areas of the circuit is defined before any traces are set down. Not only does PCB zoning places like functions on a board in the same general area, as opposed to mixing them together, but it also takes into account the speed of signals in a given area and looks at the optimum location. Thought is given to the length of lines that may radiate or pick up more noise. For example one common idea is to place high-speed logic, including microcontrollers close to the power supply. In this way the decoupling of the lines is made easier and the lengths of lines or traces that might radiate or pick up noise is reduced.

Functions on the PCB that are not so critical that have slower waveforms are located further away. Typically analogue sections of the board are located even further away as they normally carry lower frequency signals. Planning the areas of the board in this way can have a major impact on the EMC performance of the PCB.

PCB design tools

PCB design tools are becoming ever more sophisticated. Even low end ones are able to provide many functions that until recently were only found in the very high end software packages.

Some PCB design tools may assist with designing for good EMC performance. Use any facilities which may be provided to the maximum extent. Using the tools will enable the best EMC performance to be gained from the PCB design.

Other precautions for PCB EMC design

There are a few other common points to improve the PCB EMC performance.

- **Oscillators:** Care must be taken when locating and designing the layout for oscillators. Any oscillator tank loops must be located away from analogue circuits, low-speed signals, and connectors. This applies both to the board, and to the space inside the box containing the board.
- **System cable assemblies:** Another key point is to design the overall system so that cable assemblies do not pass close to an oscillator or an area that includes high speed logic, including a microcomputer after final assembly. Cable assemblies can pick up and carry noise around the overall unit and in this way degrade the EMC performance.
- **Keep high speed / noisy lines away from PCB edge:** Another good tip is to run noisy or high speed lines away from the outside edge of the board. Keeping non-noisy traces away from areas on the board were they could pick up noise, such as connectors, oscillator circuits, relays, and relay drivers also helps reduce the problem.
- **Filtering:** In some instances filtering may be required on certain lines. Ferrite beads can often provide an easy method of limiting high frequency signals, and good decoupling on the board, especially for the supply lines is necessary.
- **Filtered connectors:** On some PCBs it may be necessary to use filtered connectors to remove noise. When this is done, the earthing of the connector is important. It should be possible to earth this firmly to the PCB and the chassis.

Many of the EMC issues can be eliminated by good PCB design. In fact PCB design for EMC performance is always good practice and can prevent many time consuming investigations and costly rework. If rework is required late in the design cycle it is considerably more costly than if it is built into the design at the outset. PCB design for EMC is therefore one of the keys to a successful design.

One of the major factors with any electronic design is the emission and reception of electromagnetic noise. This can be a major challenge for many electronic development engineers as some of the issues can be a challenge to solve.

One of the key factors is the mode of used for carrying the noise: common mode and normal mode noise. Each of these modes for the noise transmission requires a difference filter configuration.

EMI noise modes

When looking at EMC and EMI issues, it is necessary to consider the mode or way in which the noise is being carried.

- **Normal mode EMI noise:** Normal mode EMI noise is the first way in which we tend to imagine noise being carried on any cable. The noise currents flow out along one conductor and back along the other. This makes a compete circuit for the noise currents. Typically, screening will provide a great amount of immunity against this form of noise as the inner conductor or conductors are screened from pick-up or radiation of the noise.
- **Common mode EMI noise:** Common mode noise can be a little more difficult to imagine. The currents may flow in the same direction on the lines of a cable - they may even flow along the screening as well, making the screening ineffective.

The currents that flow are caused by a current that has leaked out via the floating electrostatic capacitance of the load retained against the earth and has then returned to the noise source via the earth. The current may be caused by a direct connection between the load and noise source without going through the earth.

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